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A SURVEY OF AIR AND POPULATION LEAD LEVELS IN SELECTED AMERICAN COMMUNITIES

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Cincinnati University

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A SURVEY OF AIR AND POPULATION LEAD LEVELS IN SELECTED AMERICAN COMMUNITIES

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SUMMARY

The concentration of lead in the ambient atmosphere was determined at 59 sampling sites in eight American communities during the period 1968-71. Nineteen sampling sites had existed in a similar survey in 1961-62. At 14 of these sites the lead-in-air value was found to be higher in the current study than in 1961-62. The observed annual mean atmospheric concentration of lead varied from 0.14 $\mu g/m^3$ (Los Alamos) to 4.55 $\mu g/m^3$ (Downtown Los Angeles). Higher lead values were associated with urbanization.

The concentration of lead in the blood of specific well-defined populations was determined. Such populations lived in geographic proximity to specific air sampling sites. In the three metropolitan areas from which both urban and suburban population groups had been obtained, the mean blood lead levels were significantly higher in the former. In two of the three areas the blood lead level was higher in urban smokers and non-smokers than in the corresponding suburban populations, classified by smoking habits. At each location the concentration of lead in the blood of smokers was greater than that in the blood of non-smokers. The magnitude of the observed urban-suburban difference (for populations comparable in smoking habits) ranged from 0.9 μg/100 gms to 4.5 μg/100 gms. It is probable that these observations partially reflect lead absorption from ambient atmospheres differing in lead concentration. There was no significant concordance between the ranking by site of mean air lead levels and that of the mean blood lead levels prevalent in the related populations.

The observation that urban levels of blood lead are higher than suburban levels, but that air concentrations of lead are not clearly reflected in blood lead levels on a general national basis, suggests that factors other than the atmospheric lead level are of relatively greater importance in determining the blood lead levels in population groups.

No relationship was established between age of participant and the blood lead level. In husband-wife pairs, presumably exposed to similar diets and atmospheres, the males had significantly higher blood lead levels than did the females. This difference could not be attributed to smoking habits or to hematocrit levels. The possibility that the difference was due to dissimilar quantities of foods in the respective diets of men and women was not examined.

Studies of dietary lead levels showed them to be generally lower than commonly reported in the literature, 100 μg/day being a closer approximation in the population studies than the widely quoted 300 μg/day.

PREFACE

In 1958, the Surgeon General of the Public Health Service appointed a committee to provide advice relative to the health implications of the use of lead anti-knock compounds in gasoline formulations. The committee concluded that an increase in the tetraethyl lead content of gasoline from 3.0 to 4.0 milliliters per gallon would not pose a hazard to the public health from air pollution. It was recommended that studies be conducted to provide more definitive data on levels and trends of atmospheric lead levels in selected urban locations and on the blood levels of lead in selected population groups[1].

In response to these recommendations the Surgeon General formed a Working Group on Lead Contamination to develop and execute a suitable program of studies. This Group included representatives of the petroleum, automotive, and fuel additive industries, the Public Health Service, the California State Health Department, and the University of Cincinnati. With the guidance and support of the Working Group air was sampled over a 12-month period at a number of locations in Cincinnati, Los Angeles, and Philadelphia. Blood and urine samples were obtained from selected population groups in these cities.

The findings based upon these extensive observations were reported in 1965 in an official Public Health Service document: "Survey of Lead in the Atmosphere of Three Urban Communities", Publication No. 999-AP-12.[2] This report presented average, maximum, seasonal, and diurnal atmospheric lead data. These showed, among other things, that the higher lead levels were associated with areas of high vehicular density, the fall and winter months, and early morning peak traffic. The study of lead in the blood showed a tendency toward higher concentrations in groups of persons as they varied from rural to center-city areas in their places of residence and work. A number of factors appeared to be related to these observations: geographical region, tobacco smoking, occupational exposures. The Working Group also evaluated the influence of interlaboratory variation, since the required assays were performed by several collaborating organizations.

It was a primary purpose of the investigation to establish a baseline for the lead content of the atmosphere and in selected population groups. Those responsible for the work anticipated a subsequent study, which would reflect changes in these lead levels which might be attributed to various relevant factors: vehicle density, lead content of fuels, mechanical condition of vehicles, local climatology, and population patterns.

The work reported here summarizes studies conducted in 1968-72 to examine those changes, if any, which had occurred during the interval since 1962. The investigations were conducted by the Department of Environmental Health, Kettering Laboratory, University of Cincinnati with the financial support of the Environmental Protection Agency; the American Petroleum Institute; and the International Lead Zinc Research Organization, Inc. The course of the study was guided by the Subcommittee for the Surveillance of Air and Population Lead Levels, which reflects the public health interests of government and industry. The Subcommittee is a working unit of the Lead Liaison Committee, an advisory group to the Environmental Protection Agency.

PURPOSE

The purpose of the investigative program reported here was to:

1) Determine whether or not a change in the concentration of airborne lead had occurred after an interval of 8 years, at a series of reference locations designated in 1961-62.

2) Determine the ambient atmospheric levels of lead at selected additional sites in the cities studied in 1961-62 and in other communities.

3) Examine the extent to which levels of lead in the blood of selected population groups reflect exposure to lead at various levels in community atmospheres.

4) Determine whether or not a change in the blood levels of lead had occurred after an interval of 8 years in selected population groups.

PARTICIPATING ORGANIZATIONS AND ACKNOWLEDGEMENTS

The Subcommittee for the Surveillance of Air and Population Lead Levels, which provided guidance during the study, included representatives from the American Petroleum Institute, Automobile Manufacturers Association, E.I. du Pont de Nemours and Company, Ethyl Corporation, International Lead Zinc Research Organization, and the Environmental Protection Agency. Names of individual representatives appear in the appendix. Environmental studies were conducted with the cooperation of local organizations in each area: Chicago Department of Air Pollution Control, District of Columbia Department of Public Health, Houston Department of Public Health, Los Alamos Scientific Laboratory, Los Angeles County Air Pollution Control District, New York City Department of Air Resources, Philadelphia Health Department, and City of Vernon Health Department. Private citizens, commercial establishments, and public institutions generously permitted sampling stations to be installed and operated on their property.

The collection of biological materials was made possible through the cooperation of church and public service organizations.

The design and execution of this study depended upon scientific and technical competence in many areas. Names of principal participants appear in the appendix. This study is based upon their individual and collective contributions.

Financial support for the investigations reported here was provided jointly by the American Petroleum Institute, the International Lead Zinc Research Organization, and the Environmental Protection Agency (Contract PH 22-68-28).

METHODS AND PROCEDURES

The program of aerometric and biological studies was conducted in eight regions reflecting a range of geographic and climatological characteristics. The selection of Cincinnati, Philadelphia, and Los Angeles was based on the fact that extensive sampling had been conducted in these areas during a 12-month period in 1961-62, and that comparisons could now be made between current observations and those obtained some 8-9 years earlier. Investigations of a similar nature were included in the current study in the additional areas of New York City, Metropolitan Washington (D.C.), Greater Chicago, Houston, and Los Alamos, New Mexico. New York was selected because of its high vehicle

and population density and Washington because of its lack of industrialization. Chicago and Houston were added as examples of large "northern" and "southern" cities, respectively. Los Alamos represented an area with a well defined population of over 15,000 persons with minimal exposure to atmospheric metals.

Aerometric Sampling

Location of Sampling Sites

To permit an accurate appraisal of changes which may have occurred since 1961-62 in atmospheric levels of lead, stations which existed in the study conducted at that time were duplicated in the current investigation. This procedure was followed primarily for comparison purposes; the suitability or epidemiological significance of these individual sites was not reconsidered. A comprehensive photographic record of the instrument installations in 1961-62 permitted accurate duplication of station position and orientation. Certain limited changes were made in the distribution of stations in the current study as opposed to their distribution in 1961-62:

Cincinnati: Two stations (#34,35) approximately 2 miles apart and 24 miles northwest of Downtown Cincinnati were established on farms in the town of Okeana, Ohio, near the Indiana line. The purpose of these stations was to provide a rural "background" level for atmospheric lead in a locality with a population available for sampling.

Philadelphia: The station at the Philadelphia Airport (#10) was omitted because of small biological significance and major changes in the composition of aviation fuels since 1962. Station #15 at 15th and Market was moved one block east because of construction at the original site. An additional instrument (#18) was installed on the 3rd floor balcony of an apartment on Rittenhouse Square so as to record representative exposure of a center-city population. Two additional stations (#19,20) were installed in the suburban area of Ardmore-Wynnewood, where a population was to be sampled.

Los Angeles: Station #2 was moved approximately 1/4 mile north because of operational problems at the original location.

In the 5 regions where long-term sampling of this type had not been conducted previously, sites were selected on the basis of relevance to population exposure, accessibility, and the area to be covered. In communities in which biological sampling was to be conducted, emphasis was placed on selecting an instrument location which would reflect, insofar as possible, the usual human exposure in that general neighborhood. In some locations, elevations of the sampling instruments did not approximate those of the breathing zones of the study population. For particulates of respirable size, however, the evidence is that differences in elevation, such as existed in this study, influence air lead concentrations only insofar as such elevations reflect distance from the lead source.

It is essential to emphasize that all stations, although representing certain types of neighborhoods, elevations, and proximities to major roadways, were selected arbitrarily. Data from a specific site have meaning for that site only, and pooling or "averaging" for an entire city has limited validity.

Alternative sites could have been selected to yield other "averages" for each city. It would therefore not be judicious to make unqualified inference from the findings of a number of stations in a city or other area to that city or area; for example, the findings from eight selected locations in Los Angeles cannot be generalized to the "situation in Los Angeles". Pooled data for a city may have validity in certain kinds of comparisons over a period of time for the specific sites included in the pool. These data, however, cannot be precisely compared with pools based upon other combinations of sites arbitrarily selected.

The location of sampling sites in the various regions is shown in Figures 1-8.

Sampling Equipment

The equipment utilized in this study has been described[2]. In essence it consists of a filter holder for 106-mm Millipore filters (Type WS), a vane pump and motor unit drawing a nominal free air volume of 5.9 cfm, a cooling fan, and suitable electrical and air connections. The housing is constructed of plywood and is designed to permit necessary ventilation of the equipment while attenuating objectionable pump noise. Initial and final air flows through each filter are determined from orifice meter measurements.

Sampling Methods

Sampling units were operated over a 12-month period at each site. Filters were changed in most locations on Monday, Wednesday, and Friday. Because of previous experience in Los Angeles with filter obstruction in the course of 48-hour weekday exposures, tandem units with automatic switch-over permitted the collection of 24-hour samples in parts of the City with relatively high traffic density or industrialization. No problems of filter obstruction were encountered.

Filters were numbered, conditioned in a controlled atmosphere, and weighed in Cincinnati prior to exposure. Shipments of filters, each in a plastic Petri dish, were made to monitors in each city. Monitors recorded on each dish orifice meter measurements before and after exposure, the duration of each exposure, and notes (if any) about station operation. Exposed filters were returned by mail to Cincinnati in their original dishes. Upon receipt, the filters were again conditioned and weighed in the determination of total particulate weight. Calibration curves for each orifice meter permitted the determination of volume of air which had passed through each filter. A glass template was used to divide each filter into ten equal wedges suitable for analysis.

Analytical Methods

Lead contained in particulate matter on the filter wedges was determined in 1961-62 by the dithizone colorimetric technique.[2] The three laboratories cooperating in the study at that time modified the method slightly to suit the needs of each. Interlaboratory comparisons were conducted to standardize the analytical bases upon which inferences were drawn.

The developments in atomic absorption spectrometry (AAS) since 1961-62 indicated that greater efficiency in filter analysis might be achieved in the

Text continued on page 10

Figure 1.
Sampling Sites - Los Angeles

Site No.	Classification	Height above Ground, Feet	Location
1	Commercial	80	Downtown - Air Pollution Control District Headquarters
2*	Commercial	5	La Brea District - Telephone Company
3	Residential	5	Arcadia - County Aboretum
4	Residential	15	Pasadena - Fire Station
5	Residential	60	Pasadena - California Institute of Technology
6	Residential	40	Westwood - University of California
7	Industrial	5	Vernon - City Health Department
8	Commercial	95	Downtown - County Health Department

* Moved approximately 1/4 mile north of the 1961-62 site because of changes there.

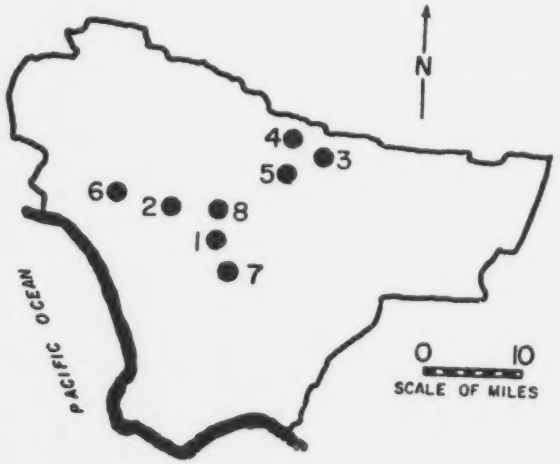

Figure 2.
Sampling Sites - Philadelphia

Site No.	Classification	Height above Ground, Feet	Location
11	Mixed	5	United States Naval Hospital
12	Commercial	50	City Health Department
13*	Commercial	5	City Hall
14	Industrial	25	Frankford Avenue - Air Pollution Control Laboratory
15	Residential	15	Pennypack Home Ownership Association
16	Mixed	10	Byberry Road - Private Residence
17	Residential	10	Eva and Dearnley - Water Treatment Plant
18	Residential	20	Rittenhouse Square - Apartment
19	Residential	10	Ardmore - Playground
20	Residential	5	Wynnewood - Private Residence

* Moved across street from 1961-62 site (construction).

Note: Original station #10, Philadelphia Airport, omitted because of insufficient biological relevance and major changes in aviation fuel.

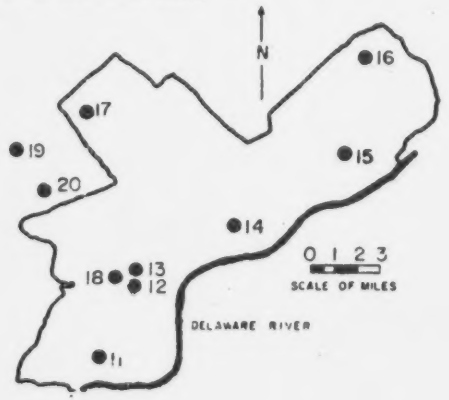

Figure 3.
Sampling Sites - Cincinnati

Site No.	Classification	Height above Ground, Feet	Location
30	Commercial	70	Downtown - Main Library
31	Residential	40	Kettering Laboratory
32	Industrial	45	Vine and Seymour - Fire Station
33	Park	15	French Park
34	Farm	5	Okeana
35	Farm	5	Okeana

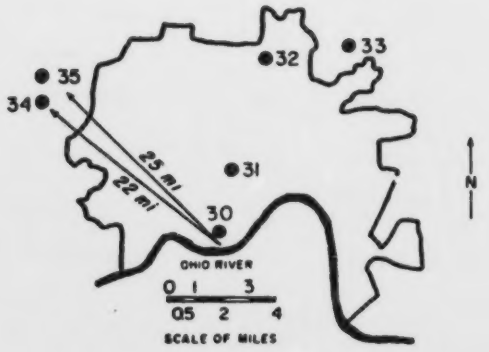

Figure 4.
Sampling Sites - Los Alamos

Site No.	Classification	Height above Ground, Feet	Location
41	Residential	15	Diamond Drive - Grammar School
42	Commercial	15	Store - Community Center Plaza

Figure 5.
Sampling Sites - Houston

Site No.	Classification	Height above Ground, Feet	Location
50	Residential	5	Cullen Road - Fire Department
51	Commercial	45	Hermann Park - Health Department
52	Commercial	15	Downtown - Christ Church Cathedral
53	Commercial	25	Downtown - Coliseum
54	Mixed	5	Market Street - Fire Department
55	Residential	5	Settegast Street - Fire Department
56	Residential	5	Latexo Drive - Private Residence

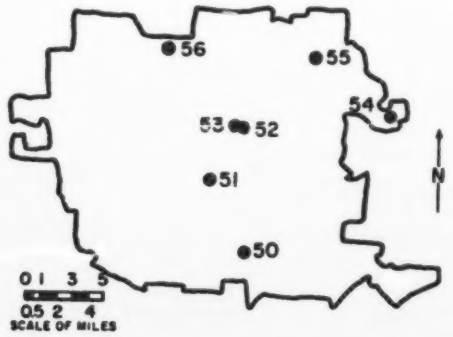

Figure 6.
Sampling Sites - Chicago

Site No.	Classification	Height above Ground, Feet	Location
60	Residential	40	Fenger High School
61	Mixed	40	Hyde Park High School
62	Residential	25	Lindblom High School
63	Mixed	25	Bridgeport - Benton House
64	Commercial	110	Downtown - GSA Building
65	Residential	50	Austin High School
66	Residential	15	Lombard - Hammerschmidt School
67	Mixed	40	Lakeview High School
68	Residential	40	Taft High School

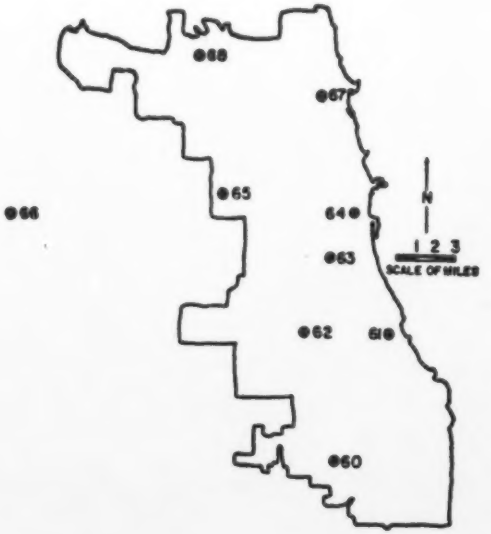

Figure 7.
Sampling Sites - Washington

Site No.	Classification	Height above Ground, Feet	Location
70	Residential	20	Arlington - Health Department
71	Commerical	75	Indiana Avenue - Municipal Building
72	Commercial	5	New Jersey Avenue - CAMP Station
73	Residential	40	Anacostia - Nevel Thomas School
74	Residential	5	Woodley Park - Embassy of Switzerland
75	Farm	5	Virginia Route 7 - Jarrett Farm
76	Residential	5	Bunker Hill Road - Children's Convalescent Hospital
77	Residential	5	Bethesda - Private Residence

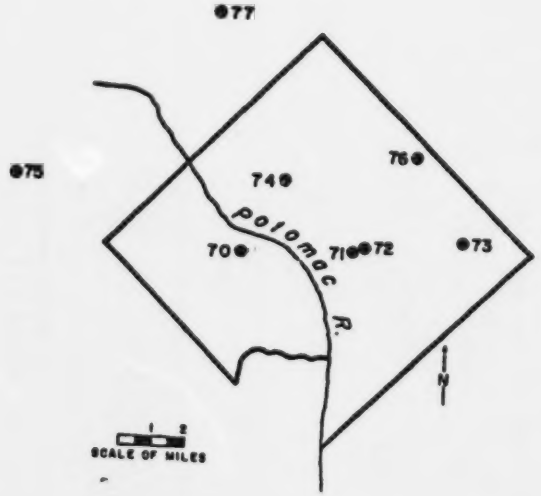

Figure 8.
Sampling Sites - New York

Site No.	Classification	Height above Ground, Feet	Location
81	Mixed	50	Bronx - Bronx High School
82	Mixed	50	Harlem - 121st Street Laboratory
83	Residential	60	Queens - Jackson High School
84	Residential	45	Brooklyn - Brooklyn College
85	Mixed	40	Greenwich Village - Northern Dispensary
86	Residential	20	Staten Island - St Anne School
87	Residential	5	Staten Island - Mohlenhoff Nursery
88	Residential	25	Port Washington - South Salem School
89	Residential	20	Port Washington - Daly School

current study with this method. Consequently this procedure was adopted with special attention to an examination of the relationship between analytical results obtained by these two methods: dithizone and AAS. Since a primary purpose of the entire study was the determination of changes in air lead concentrations over a time interval, it was essential to assure that demonstrated differences were not due to variations in technique.

Methodological checks were of two types: 1) assays of wedges from the same filter by dithizone and AAS; and 2) assays of retained wedges from the 1961-62 study by current analytical techniques (AAS).[3] In each type of evaluation it is apparent that wedges from the same filter do not contain the same amount of lead; i.e., there is inter-wedge variation. The magnitude of inter-wedge variation was examined as a part of the consideration of variation between methods. It was determined that the precision with which the quantity of lead on a filter may be inferred by the analysis of one 10% wedge is inconsistent from one filter to the next. Presumably this inconsistency reflects to some extent particle size and influence on some filters of deposited heavy particles which appear on only a few segments of the filter. In the estimation of lead on a filter from one 10% wedge, the 95% confidence limits may be as narrow as 97-103% of the mean for the entire disc or as wide as 67-150%, depending upon whether one uses the lower or upper estimate of interwedge variance. In a general pool of analyses, however, it was determined that the 95% confidence limits for the lead content of a filter disc as estimated from a 10% segment is 85 to 120% of the mean. For most stations approximately 150 10% wedges were collected over the course of 12 months; the site average is based upon 150 analyses.

The relative response of the atomic absorption method as compared with that based upon dithizone colorimetry was found to vary between 0.92 and 0.98. This observation approximates the 0.95 average value which had been obtained from lead determinations on filters artificially spiked with lead (95% confidence limits 0.93-0.97).

To construct a direct relationship between assays in 1962 and in 1969-71, retained wedges of filters which had been exposed, cut, and assayed at the earlier date were examined in the current study. There is of course variation between wedges from the same filter. A variation between 1962 and 1969-71 methodologies exists in addition to the interwedge variation. Table 1 summarizes a comparison of analyses of single 10% wedges in 1969 with single 10% wedges from the same filters in 1962.

Table 1. Comparison of Analytical Results From Duplicate Analyses of Wedges From a Single Filter.

City	Av. ratio (%) 1969/1962	No. of filters	No. filters with ratio < 1	No filters with ratio > 1	z-Value
Los Angeles	103.47	39	16	19	1.28
Cincinnati	90.86	40	30	6	-6.29
Philadelphia	99.61	40	18	20	-0.21

The magnitude of the z-value reflects the degree of difference between the number of filters with ratios less than and more than one. The 5% critical value is $\pm$ 2.68. It is therefore concluded that the 1969 air lead concentration determinations in Cincinnati are systematically significantly lower than those obtained in 1962 ($z = -6.29$), the average ratio being 90.86%. Interpretation of the air lead concentrations at the Cincinnati sites in 1969 must give this observation appropriate weight. For Los Angeles and Philadelphia no significant differences were found between the 1962 and 1969 measurements.

Meteorological Considerations

The previous study (1961-62) demonstrated that storm conditions with strong winds were associated with low atmospheric lead levels; precipitation alone produced no significant effect nor did flooding, snow cover, or high space heating demands on cold days.

To determine whether or not unusual meteorological conditions might have influenced the observations reported here on the atmospheric levels of lead, a brief examination was made of the representativeness of the sampling period. Significant deviations from conditions recorded in 1961-62 might have important influences upon the conclusions to be drawn from the current study.

Meteorological data obtained at the Greater Cincinnati Airport are summarized in Figure 9. Precipitation during the sampling period was somewhat below normal, especially in late winter. Heating requirements were slightly less than normal. Average wind speeds were near normal and higher in the winter than in the summer months. The overall situation appears to approximate that which existed in 1961-62 and is not inconsistent with the 30-year average.

Meteorological data obtained at the Los Angeles International Airport are summarized in Figure 10. January precipitation totalled 9.6 inches, a significant departure from normal. Average monthly wind speed for the year was consistently higher than the 30-year average. Average wind speed in 1968-69 was higher than in 1961-62 except in the month of May. Advisory statements of high air pollution potential for Los Angeles were issued for May 10-11 and November 3-5, 1969. An increase in total particulate matter and atmospheric lead levels at these times was observed at most sites. In 1961-62 the relatively high concentrations of atmospheric lead in the fall and winter were attributed in part to relatively low wind speeds during these seasons. For 1968-69, atmospheric lead levels during these months was again relatively high as compared to those recorded in spring and summer months, the differential being somewhat greater than observed in the previous study. The average monthly wind speed in 1968-69, however, varied less than in the previous study.

With respect to Philadelphia, precipitation was generally below normal and the 1961-62 level except for the very wet summer in 1969. Heat requirements for the two test periods and the 30-year average were consistent. Wind speed in the winter of 1968-69 was significantly greater than the 30-year average; in 1961-62 wind speed had been less than average. Inspection of atmospheric lead concentrations as recorded 1961-62 and 1968-69 shows that lower levels or relatively small increases were recorded during these relatively windy winter months of 1968-69, as compared with the corresponding still months of 1961-62. An

advisory of high air pollution potential in the Philadelphia area for September 23-24, 1969, was not associated with unusually high levels of atmospheric lead, although total particulate matter increased at all sites.

Corresponding meteorological data for Los Alamos are not published; however observations during the test year do not indicate major departures from normal.

Meteorological data recorded at Central Park in New York City indicate that precipitation was approximately half of normal during the summer of 1970. Heating requirements approximated normal levels except for November and December, which were cold. The average wind speed for the test period was slightly less than normal except in December, 1970.

Precipitation recorded in Chicago during 1970-71 was generally well in excess of normal. Heating requirements were somewhat below normal for the year. Wind speeds were slightly above the 30-year average in March and October, 1970.

Corresponding data for Houston show that 14.39 inches of rain fell in May, 1970, more than three times normal; positive and negative departures from normal occurred throughout the year. Heating requirements approximated the 30-year average. Throughout the year the average monthly wind speed was less than normal by approximately 20-30%.

Meteorological data obtained at Washington National Airport are summarized in Figure 15. Precipitation for the year approximated the normal rainfall. High air pollution potential advisories on April 29-30, June 9-12, July 28, and August 15-16, 1970, were not associated with significant elevations in the air concentrations of lead. Heating requirements and wind speeds approximated the 30-year mean.

Biological Studies

Population Selection

A principal objective of this investigation was an evaluation of the relationship between atmospheric lead levels and the concentrations of lead in the blood of persons exposed to the atmospheres in question. While a number of different population groups have been studied in attempts to establish this relationship, multiple uncontrolled variables associated with these groups have confused the appraisal of the actual exposure and the construction of the correct inference. In the absence of personal monitoring devices one cannot establish the total integrated exposure over months or years of police officers, garage mechanics, "drivers", "commuters", aircraft workers, or other similar groups. Occupational and wide-ranging geographical factors are not reflected in air sampling at fixed locations not clearly related to the population in question.

For these reasons particular attention was focused in this study on the definition of populations with a specific consistent relationship to known air levels of lead. Populations sampled in this study were derived from women volunteers living within a prescribed region surrounding an air sampling instrument. Women, in general, currently tend to spend a greater proportion of their time at home or in the neighborhood of their home than do men. Furthermore, women who are employed at a distance from their homes rarely work in lead-using trades. For inclusion in the study a continuous residence time of not less than 5 years

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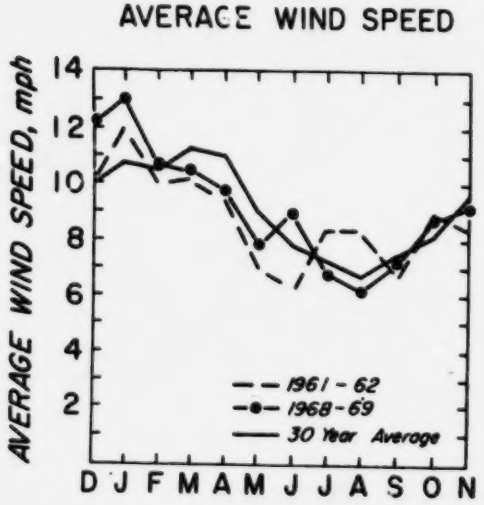
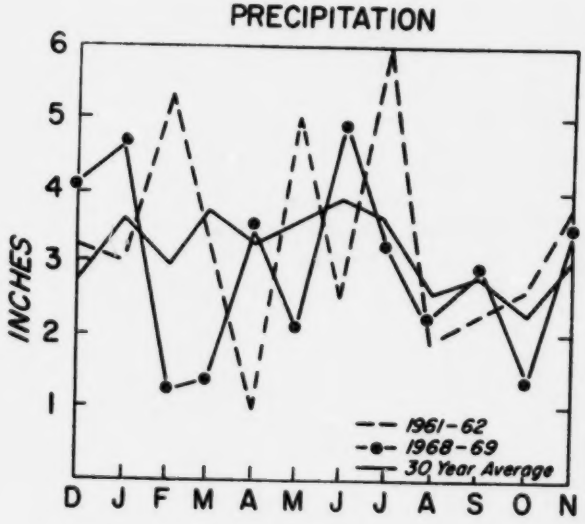




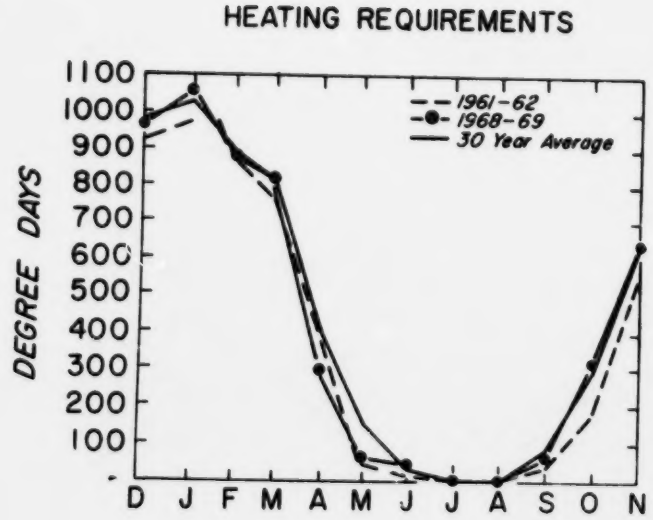
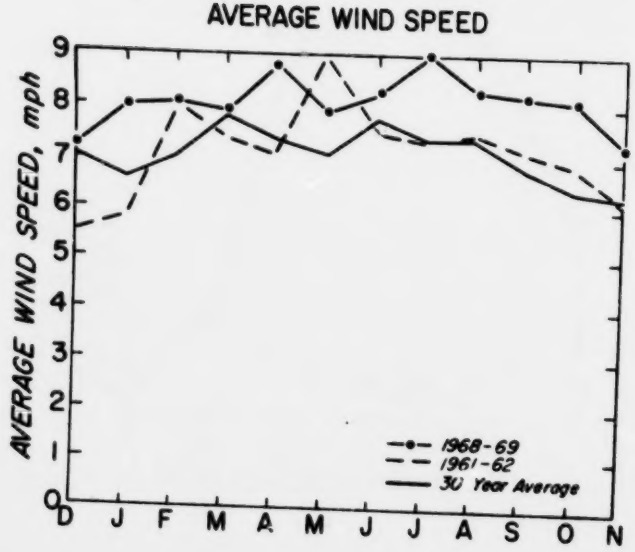
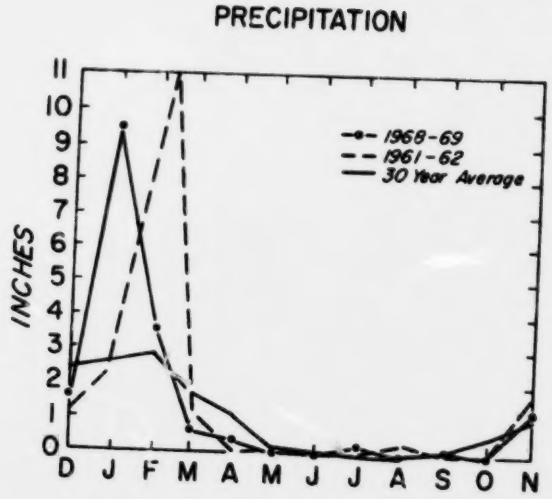


Figure 9
Meteorological Factors
Cincinnati





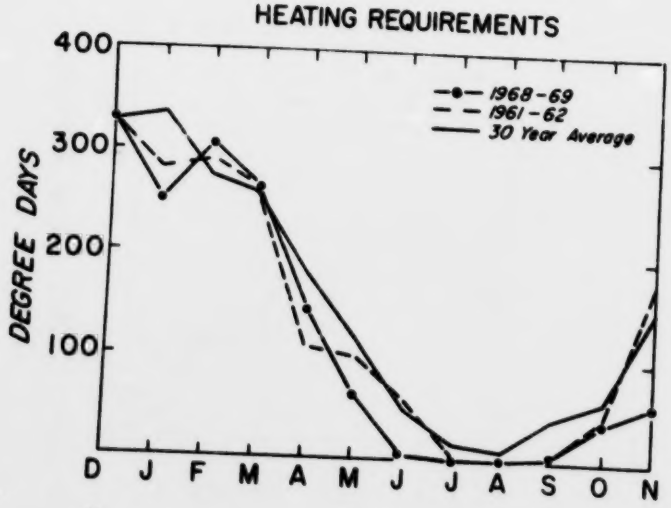
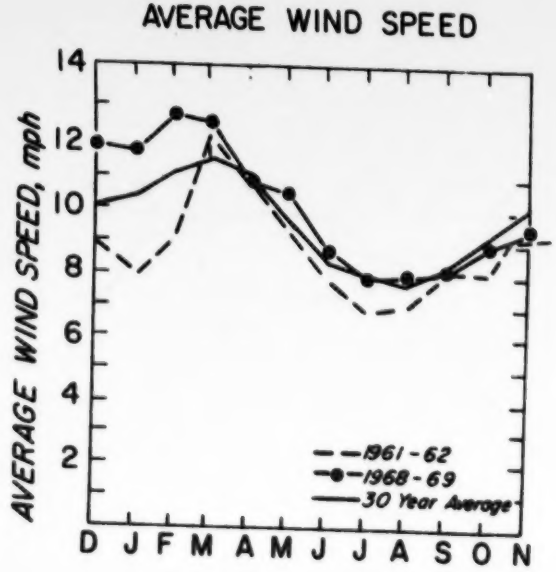
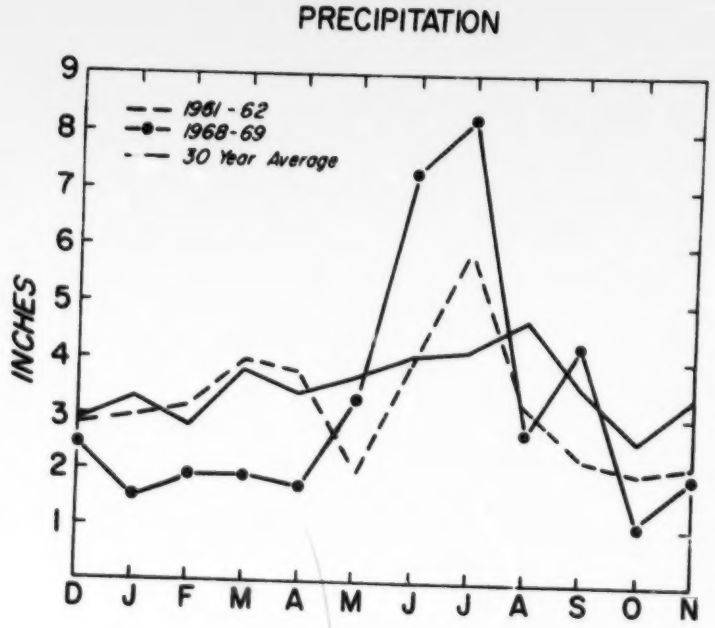


Figure 10
Meteorological Factors
Los Angeles





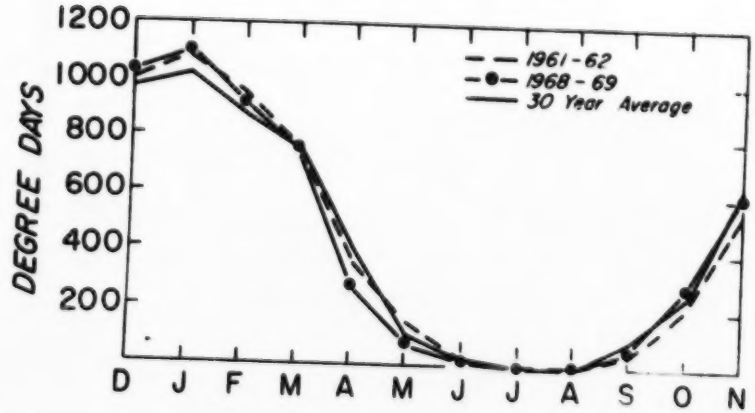
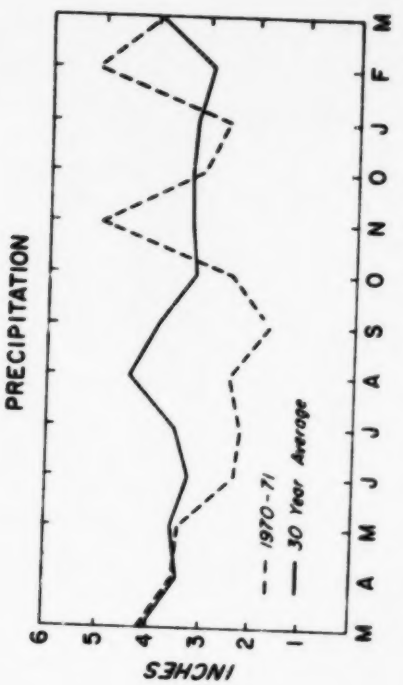
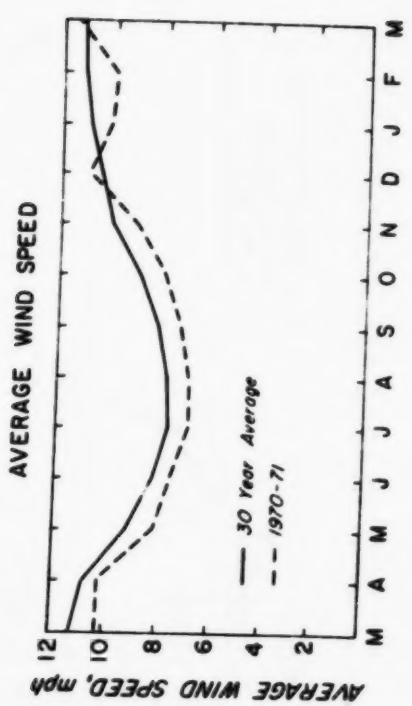


Figure 11
Meteorological Factors
Philadelphia





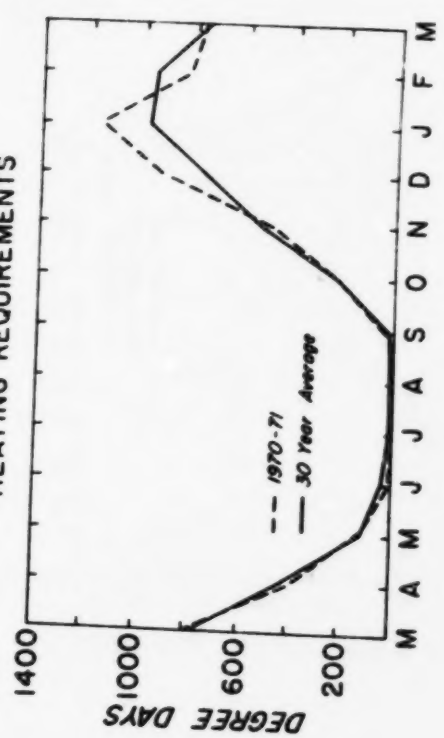
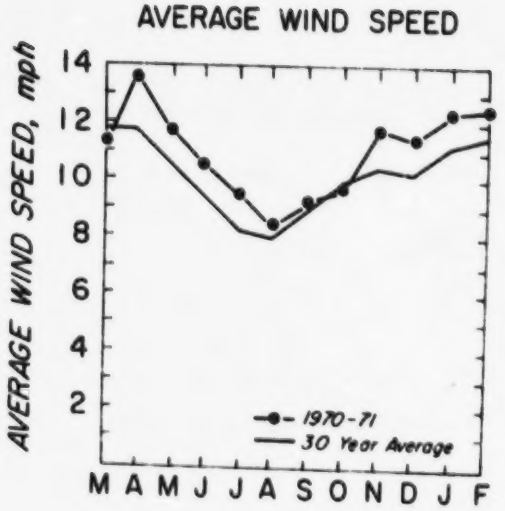
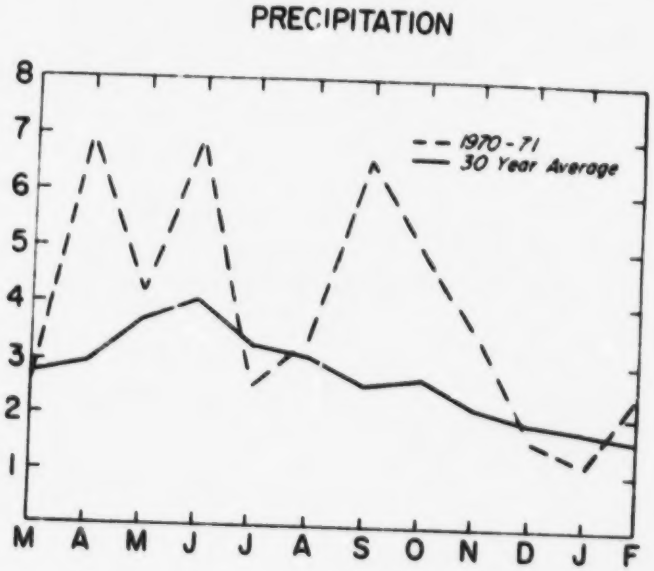


Figure 12
Meteorological Factors
New York





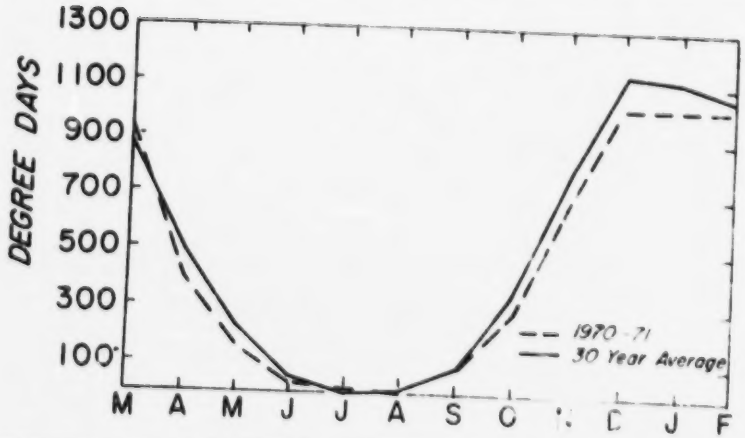
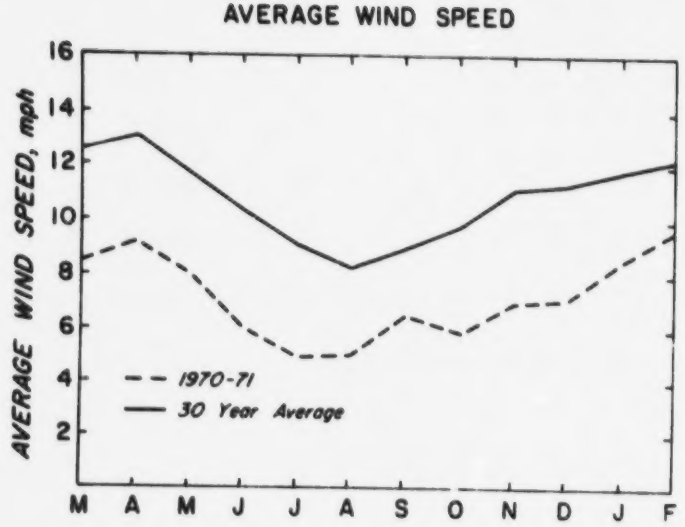
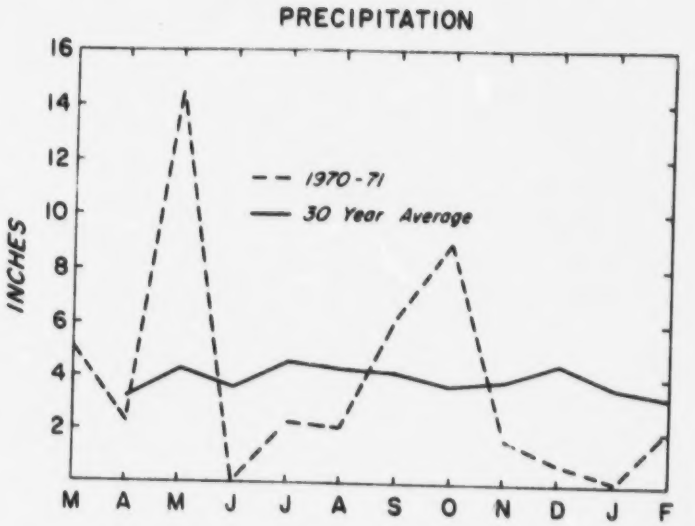


Figure 13
Meteorological Factors
Chicago





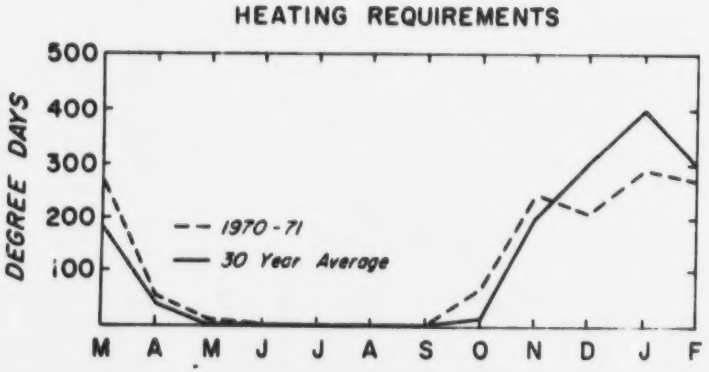
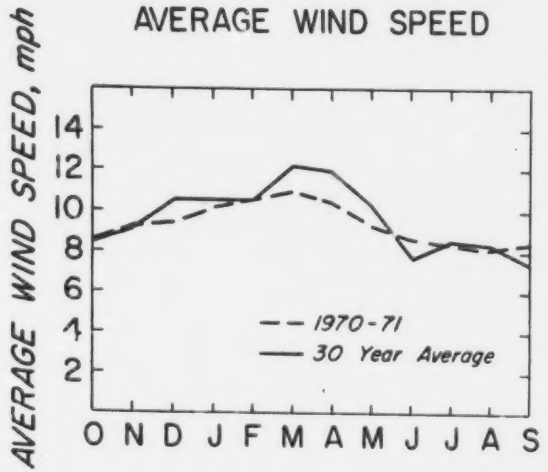
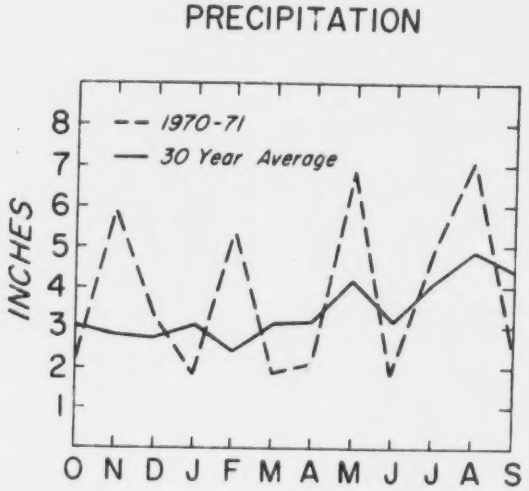


Figure 14
Meteorological Factors
Houston





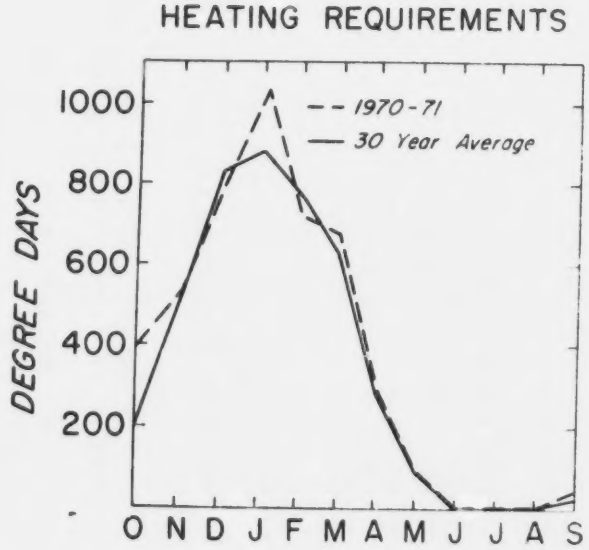


Figure 15
Meteorological Factors
Washington

within this area was required. The area was defined either by political boundaries ("Pasadena", "Port Washington") or by the circumference of a circle one mile or less in radius drawn from the reference station. Homogeneity of land use within each area was reasonably consistent. This study was concerned exclusively with absorption of ambient community atmospheric lead via the respiratory system and did not involve pediatric exposures nor exposures of men with a variety of possible occupational opportunities for additional lead absorption. The extent to which blood lead levels in women reflect levels in the general population was not examined.

An attempt was made to sample "suburban" and "urban" populations in several of the regions under study. In some areas this objective was confounded by the fact that highly mobile populations and rapidly changing neighborhoods made it unlikely that a group of acceptable volunteers could be recruited without extensive personal solicitation. In the same region a comparison of "suburban" and "urban" populations would tend to minimize the influence of regional factors which might influence regional biological lead levels. Climate and sources of food and water would tend to affect equally populations living in the same general metropolitan area. Populations sampled in the current study are presented in Table 2.

Table 2. Population Groups Sampled

Community	Urban				Suburban			
	Station	N	N*		Station	N	N*
Philadelphia	Rittenhouse Square	18	137	136	Ardmore-Wynnewood	19, 20	156	150
Cincinnati					Okeana (rural)	34, 35	166	162
Los Angeles	Pasadena	4, 5	209	193				
Los Alamos					Los Alamos	41, 42	204	191
Washington	{Woodly Park / Cleveland Pk.}	74	224	219				
New York	Greenwich Vil.	85	140	140	Port Wash.	88, 89	203	198
Chicago	Bridgeport	63	148	147	Lombard	66	208	208
Houston	Nw. Houston	56	204	191				

*All statistical computations performed on populations corrected to exclude those persons with possible unusual lead exposure and those who were less than 20 or more than 79 years of age. See p. 31.

In addition to the groups of women which participated as described, smaller studies were conducted in four other populations.

1) Husbands of 100 women participants in Los Alamos were sampled to see whether or not there is a male-female differential in the blood level of lead. It was possible to define the occupational exposures of these men, most of whom were employed by the Los Alamos Scientific Laboratory. The atmosphere at the Loboratory does not vary from that in the residential areas. Husband-wife pairs

were considered to consume approximately the same foods, although the quantity consumed by the husband will, of course, generally exceed that consumed by the wife. In the absence of occupational lead exposure and under these circumstances it was believed that the degree of difference in male and female blood lead levels could be determined.

2) In 1962, blood levels of lead were determined in 120 Cincinnati police officers. In 1971, it was possible to identify 65 of these men still on the police force. Of these 48 volunteered to provide blood samples. The purpose of this study was to see whether or not blood lead levels had changed in this population over the course of 10 years. Such changes as might be observed could be attributed to the effect of aging or to actual differences in absorption over the intervening period.

3) A group of 87 men and women residents of the Pennypack Woods section of north-eastern Philadelphia was studied in April, 1961, as representative of a "suburban" population. Of these 44 had moved from the neighborhood by April, 1971; 5 more had died. Of the remaining 38, it was possible to obtain blood samples from 23 persons in 1971.

4) The report issued in 1965 included blood lead data from assays performed on 37 men and women who had participated in a multiphasic screening program in Alpine County, a rural area in the Sierra Nevada. Most of these persons were of American Indian ancestry and had lived in the County for most of their lives. Blood samples were obtained in October, 1971, from 39 persons who had lived in Alpine County for at least 5 years. This group did not represent to a significant extent those individuals who had been sampled previously; however they were considered to be representative of persons who had been long-term residents of Alpine County.

Population Lead Levels

Data Collection: In order to examine the correlation between air and blood lead levels, it is necessary to control those variables which might be expected to influence the concentrations of lead in the blood. The selection of populations permitted residential specifications as to location and duration. Through the use of an interview, other variables were evaluated: occupation, hobbies, smoking habits, sources of food and water, medical history. The principal study was based exclusively on women, a fact which eliminated differences in blood lead due to difference in sex, and to a significant degree, in occupation and exposure.

Determination of Blood Lead Levels: Persons in the several populations studied who met the residential criteria for inclusion and who had been interviewed contributed blood samples for analysis. Blood was drawn from the ante-cubital vein into lead-free evacuated tubes of 20 ml capacity. Tubes were stored under refrigeration until the time of analysis. Assays were performed according to the standard dithizone method of Bambach and Burkey[4] as modified by Cholak and Burkey.*

There is no argument with the position that an epidemiological investigation of this type would be improved by the determination of the total body burden of lead in exposed populations. It is apparent, however, that these determinations or active clinical procedures such as provocative lead excretion tests with

*Method available upon request to J. Cholak, Kettering Laboratory, Cincinnati, Ohio 45219.

chelating compounds require experimentation upon humans in a way which cannot be currently justified in epidemiological studies. Blood lead levels do, however, reflect recent major changes in exposure and the body burden of lead, insofar as there has been long-term exposure at a relatively constant level so that a steady-state relationship between blood and the body burden exists. In the situations under examination the likelihood of recent major changes in exposure is small. If the exposure to lead has been constant over a period of time, it is reasonable to assume that the levels of lead in the blood of these populations are meaningful indices of body burden for these adult populations.

Estimation of Alimentary Lead Intake

Since lead levels in man reflect intakes from both the respiratory and gastrointestinal systems, it is not prudent to make quantitative inferences about absorption from the lungs with knowledge reflecting only total lead absorption. Without standardized alimentary intakes of lead or knowledge of its level in each population, a situation may exist in which differences in blood lead levels may be incorrectly attributed to variability in atmospheric lead levels. It is also true that a lack of difference in mean blood lead levels between populations may be due to compensatory variations between sources of absorption for those populations. In other words, high alimentary lead and low respiratory lead levels in one population may produce the same blood lead level which is observed in a population exposed to high atmospheric and low food lead levels. To infer that different atmospheric lead concentrations have no influence on blood lead levels is obviously incorrect in this situation which omits consideration of lead intakes in food and water.

In carefully controlled studies of lead metabolism, it has been possible to collect accurate duplicate diets of the experimental subjects, for whom alimentary lead intakes could then be determined. This approach did not lend itself to the study reported here, however, because of the cost of duplicate diets for large numbers of people and the difficulty in obtaining accurate duplicates from inexperienced people. It was determined that information of approximately the same utility might be derived from measurement of lead excreted in the feces, which contain some 90-92% of lead ingested in the diet. Accordingly 20 volunteers in each region were recruited to participate in a ten-day excretory collection. Urine and feces were collected separately in low-lead plastic containers. A measured aliquot of urine and all fecal samples were shipped to Cincinnati for assay. To assure total collections only intelligent and motivated persons were invited to participate. A detailed instruction period and daily collections of materials by a nurse contributed to the completeness of the collections.

The manner in which the metabolic study was designed reflects certain assumptions which affect its validity. It has been assumed that persons who live in a general metropolitan region derive their food and water from essentially equivalent sources, so that measurements of alimentary lead in Port Washington on Long Island also describe the situation in New York City. Similarly, measurements in Chicago or Philadelphia suburbs are applicable as well to the respective urban area. There are obviously differences between individuals in their choice of foods, but we believe that the sampling method gave a reliable index for the region. We further believe that the dietary habits of 20 people over the course of ten days are representative of the general habits of the parent population of 200 people.

It is also apparent that extrapolation of a ten-day sample to an expression of annual lead ingestion is not fully satisfactory. It is impractical, however, to sample throughout a year in the absence of compelling scientific reasons and participants with special motivations and attitudes. Since the samples used in this study were collected during times of the year when an abundance of fresh foods was not normally available, however, we believe that the ten-day sample does reflect the general situation for most of the year. Only during the summer, when fresh fruits and vegetables are more readily obtained, might there be major changes in the food sources of some individuals. We have permitted the assumption, therefore,that the sampling as described does reflect general alimentary lead intake.

Analyses of excreta for lead were conducted by the atomic absorption technique; 10% of the samples were also analyzed by duplicate dithizone procedures. In the case of the fecal samples, which were received and weighed in plastic bags, the entire sample with the bag was ashed for assay. Lead content of control bags had been determined and found to be only several micrograms per bag.

OBSERVATIONS AND DISCUSSION

The investigative program described in this report was designed to:

1) Determine whether or not a change in the concentration of airborne lead had occurred after an interval of 8 years at a series of reference locations designated in 1961-62.

2) Determine the ambient atmospheric levels of lead at selected additional sites in the cities studied in 1961-62 and in other communities.

3) Examine the extent to which levels of lead in the blood of selected population groups reflect exposure to lead at various levels in community atmospheres.

4) Determine whether or not a change in the blood levels of lead had occurred after an interval of 8 years in selected population groups.

Except in the case of the fourth objective, data were developed which are useful in answering the questions presented.

Aerometric Data

Aerometric data are presented in Tables 3 and 4. With respect to changes in atmospheric levels of lead during the interval 1961-62 to 1968-69, the reported data (Table 5) demonstrate higher lead levels during the latter period at 14 of the 19 sites which were re-established. A careful examination of experimental methodology tends to exclude the possibility that this change is an artifact reflecting changes in technique. Current assays of 1961-62 filter wedges from Los Angeles and Philadelphia have validated the lead assay techniques used during the period 1968-71. Because of the observation that filter wedges from the 1961-62 Cincinnati study, when re-assayed in 1969, yielded results approximating 91% of those obtained in the earlier period, it is possible that increases in atmospheric lead levels at the re-established Cincinnati sites are greater than may be apparent. Consequently, increases in the current study can hardly be

Text continued on page 30

TABLE 3

Monthly Mean Concentrations of Lead in Los Angeles, Philadelphia, Cincinnati, and Los Alamos, 1968-69
(in micrograms per cubic meter of air)

City	Site	Month											
		D	J	F	M	A	M	J	J	A	S	O	N
Los Angeles	1	5.8	4.2	3.5	3.9	4.4	2.9	2.4	3.1	4.8	4.6	5.0	5.2
	2	5.7	5.2	4.5	4.6	3.4	2.9	2.6	3.6	4.1	4.3	6.6	6.8
	3	5.0	3.8	3.2	4.1	2.8	2.7	2.1	2.9	3.7	4.2	4.3	3.9
Pasadena	4*	5.3	3.5	3.0	3.5	2.9	3.2	2.7	3.7	5.1	5.4	3.8	3.7
Pasadena	5*	3.7	2.3	2.7	3.3	2.1	2.8	2.2	3.2	4.2	4.4	3.5	3.3
	6	2.9	2.0	1.9	3.1	1.8	2.3	1.4	2.3	3.5	3.0	3.9	1.6
	7	7.0	5.0	2.7	3.8	2.6	2.3	1.7	2.4	3.2	3.6	4.5	5.1
	8	7.6	5.6	4.7	5.2	3.5	3.0	2.5	3.4	5.2	5.1	5.3	6.1
	All sites†	5.2	3.7	3.2	3.9	2.8	2.7	2.2	3.0	4.2	4.3	4.5	4.1
Philadelphia	11	2.1	1.8	1.6	1.7	1.3	1.4	1.6	1.9	2.2	2.7	2.6	2.4
	12	1.9	1.9	1.4	1.6	1.2	1.5	1.4	1.8	1.8	2.6	2.2	2.1
	13	3.9	3.4	2.6	3.5	3.2	3.0	3.7	4.4	3.8	5.1	5.1	4.1
	14	2.3	2.1	1.5	1.8	1.6	1.9	2.3	2.3	2.4	2.9	3.0	2.6
	15	1.6	1.4	0.9	1.3	1.0	1.1	1.1	1.3	1.6	2.0	1.9	2.0
	16	1.6	1.1	0.6	0.8	0.9	0.9	1.0	1.0	1.2	1.5	1.7	1.4
	17	1.3	1.0	0.6	0.9	0.9	0.9	1.1	1.2	1.2	1.5	1.3	1.4
Rittenhouse Sq.	18*	1.9	1.9	1.2	1.4	1.1	1.5	1.3	1.8	1.8	2.6	2.3	1.9
Ardmore	19*	1.5	1.3	0.8	1.0	0.9	1.0	1.1	1.4	1.7	1.7	2.1	1.5
Wynnewood	20*	1.2	1.0	0.8	0.7	0.7	0.9	0.9	1.1	1.0	1.3	1.6	1.3
	All sites†	1.8	1.6	1.1	1.3	1.2	1.3	1.4	1.6	1.7	2.2	2.2	1.9
Cincinnati	30	1.3	1.4	1.4	2.1	1.9	1.7	1.9	2.1	3.1	2.6	2.3	2.0
	31	1.2	0.8	0.9	1.7	1.2	1.2	1.3	1.5	2.6	2.1	1.8	2.2
	32	1.5	1.2	1.5	2.2	2.0	2.1	2.1	2.1	3.1	2.8	3.3	2.8
	33	0.6	0.5	0.7	0.9	0.7	0.9	0.8	0.9	1.2	1.1	1.0	1.2
Okeana	34*	0.1	0.3	0.4	0.5	0.3	0.3	0.3	0.3	0.4	0.3	0.5	0.3
Okeana	35*	0.2	0.3	0.4	0.5	0.3	0.3	0.2	0.3	0.4	0.4	0.5	0.3
	All sites†	0.6	0.6	0.8	1.1	0.8	0.8	0.8	0.9	1.3	1.1	1.2	1.0
Los Alamos	41*	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.3	0.1	0.1
	42*	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2
	All sites†	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.1

* blood sampled

† geometric mean

TABLE 3 (Continued)

Monthly Mean Concentrations of Lead in Chicago, New York, and Houston, 1970-71
(in micrograms per cubic meter of air)

City	Site	Month													
		M	A	M	J	J	A	S	O	N	D	J	F	M	A
Chicago	60	1.18	1.28	1.10	1.23	1.39	1.61	1.67	1.55	1 31	1.06	1.42	1.01		
	61	1.16	1.13	1.28	1.25	1.48	1.51	1.67	1.69	1.36	1.23	1.52	1.09		
	62	1.32	1.01	1.46	1.60	1.60	2.00	1.99	2.11	1.65	1.40	1.50	1.15		
Bridgeport	63*	1.47	1.65	1.67	1.83	1.69	1.81	2.15	2.24	1.81	1.68	2.00	1.33		
	64	1.42	1.69	1.73	1.90	1.90	2.18	2.26	2.27	1.70	1.67	1.95	1.56		
	65	1.28	1.44	1.41	1.45	1.77	1.82	1.98	2.23	1.59	1.26	1.80	1.19		
Lombard	66*	1.04	1.09	0.98	0.94	0.90	1.23	2.74							
	67	1.05	1.34	1.29	1.48	1.82	1.77	2.13	1.90	1.78	1.42	1.63	1.38		
	68	1.42	1.68	1.51	1.64	2.46	2.70	2.65	3.52	1.84	1.23	1.70	1.28		
	All sites†	1.25	1.34	1.36	1.45	1.62	1.81	2.11	2.11	1.61	1.35	1.68	1.24		
New York	81		1.33	1.90	1.80	1.86	2.55	2.94	2.34	1.49	1.33	----	1.66	1.02	
	82		1.81	2.38	2.58	2.27	2.39	2.48	2.66	2.37	1.42	1.51	1.84	1.36	
	83		1.45	1.89	1.93	1.67	2.03	1.83	2.01	1.67	1.61	2.09	1.36	1.41	
	84		1.29	1.61	1.86	1.72	2.09	1.83	1.80	1.88	1.64	2.15	1.52	1.32	
Greenwich	85*		1.99	2.51	2.41	2.18	2.46	2.66	2.69	2.20	1.82	1.75	1.81	1.15	
	86			1.28	1.13	0.83	1.26	1.90	1.69	1.39	1.81	1.69	1.57	1.00	1.03
	87			1.14	0.90	1.10	1.56	1.61	1.51	1.43	1.24	1.26	1.34	0.87	0.94
Port Wash.	88*		1.08	1.22	1.23	1.26	1.44	1.24	1.24	1.42	0.94	0.94	0.92	0.97	
Port Wash.	89*		0.96	1.37	1.22	1.27	1.39	1.31	1.13	1.16	0.95	1.03	0.87	0.80	
	All sites†		1.37	1.64	1.58	1.50	1.85	1.90	1.82	1.63	1.38	1.49	1.39	1.08	0.98
Houston	50	0.69	1.13	1.27	1.04	1.02	1.26	1.25	2.69	1.54	0.93	0.98	0.82		
	51	0.94	0.95	1.31	0.69	1.00	0.90	0.96	1.89	1.36	0.98	0.98	0.76		
	52	2.20	2.05	2.07	1.20	1.94	2.36	2.55	3.17	2.57	2.24	2.08	1.73		
	53	2.52	2.57	2.42	1.52	1.77	2.33	3.13	4.14	2.61	1.74	2.01	1.54		
	54	1.41	1.28	1.21	1.01	1.25	1.26	1.21	1.73	2.16	1.22	1.19	1.18		
	55	1.04	0.70	0.59	0.68	0.89	0.99	0.78	1.30	1.44	0.72	0.95	0.70		
NW Houston	56*	0.69	0.85	0.94	0.85	0.97	0.78	1.13	1.18	0.91	0.70	0.74	0.63		
	All sites†	1.20	1.23	1.28	0.96	1.21	1.29	1.39	2.09	1.69	1.12	1.19	0.98		

TABLE 3 (Continued)

Monthly Mean Concentrations of Lead in Washington, 1970-71
(in micrograms per cubic meter of air)

City	Site	Month											
		O	N	D	J	F	M	A	M	J	J	A	S
Washington	70	0.97	1.57	1.41	1.03	1.34	0.68	0.91	1.26	1.04	0.93	1.16	1.18
	71	1.49	2.22	1.74	1.37	1.75	1.21	1.95					
	72	1.95	3.89	2.59	2.13	2.20	1.64	2.78	2.06	1.81	2.02	2.09	2.04
	73	1.57	2.87	2.49	1.65	2.02	1.82	1.44	1.55	1.38	1.35	1.86	1.89
Woodley Pk. / Cleveland Pk	74*	1.14	1.69	1.28	0.96	1.28	1.07	1.42	1.29	1.00	0.96	1.15	1.18
	75	1.26	1.64	1.47	1.05	1.25	0.91	0.93	0.88	1.05	0.88	1.24	1.22
	76	2.23	3.54	2.89	2.33	2.98	1.82	2.17	2.09	1.93	1.77	2.49	2.44
	77	0.97	1.82	1.12	1.00	1.19	1.19	0.77	1.24	0.94	0.81	1.07	1.13
	All sites†	1.39	2.27	1.77	1.35	1.66	1.23	1.41	1.42	1.26	1.17	1.50	1.51

Table 4
Yearly Means and Confidence Intervals of Air Pb Concentrations For Each Station

Area		Station	Geometric Mean ug/m^3)	95% Confidence Limits (ug/m^3)
Cincinnati		30	1.92	(1.63, 2.27)
Dec 1968 -		31	1.45	(1.16, 1.83)
Nov 1969		32	2.13	(1.75, 2.60)
		33	0.85	(0.71, 1.01)
	Okeana	34*	0.31	(0.24, 0.41)
	Okeana	35*	0.33	(0.20, 0.40)
Philadelphia Suburban	Ardmore	19*	1.28	(1.06, 1.55)
Dec 1968 -	Wynnewood	20*	1.01	(0.86, 1.19)
Nov 1969				
Philadelphia Urban		11	1.89	(1.63, 2.20)
Dec 1968 -		12	1.74	(1.52, 2.00)
Nov 1969		13	3.75	(3.30, 4.26)
		14	2.18	(1.90, 2.52)
		15	1.39	(1.19, 1.65)
		16	1.09	(0.90, 1.33)
		17	1.08	(0.92, 1.27)
	Rittenhouse Sq.	18*	1.67	(1.42, 1.93)
Los Angeles		1	4.03	(3.40, 4.76)
Dec 1968 -		2	4.34	(3.58, 5.26)
Nov 1969		3	3.46	(2.96, 4.05)
	Pasadena	4*	3.72	(3.20, 4.32)
	Pasadena	5*	3.06	(2.62, 3.57)
		6	2.36	(1.92, 2.90)
		7	3.39	(2.62, 4.39)
		8	4.55	(3.71, 5.60)
Los Alamos		41*	0.14	(0.11, 0.18)
Dec 1968 -		42*	0.20	(0.16, 0.25)
Nov 1969				
Washington, D.C.		70	1.10	(0.95, 1.27)
Oct 1970 -		71	1.64 (7 mo.)	(1.36, 2.00)
Sept 1971		72	2.21	(1.91, 2.55)
		73	1.78	(1.53, 2.06)
	Woodley Park }	74*	1.19	(1.07, 1.32)
	Cleveland Park }	75	1.13	(0.99, 1.28)
		76	2.34	(2.05, 2.67)
		77	1.08	(0.94, 1.24)
New York Suburban	Port Washington	88*	1.14	(1.03, 1.27)
Apr 1970 -	Port Washington	89*	1.10	(0.98, 1.24)
Mar 1971				

* blood sampled

Table 4 (Continued)

Area		Station	Geometric Mean (ug/m^3)	95% Confidence Limits (ug/m^3)
New York Urban		81	1.76	(1.44, 2.15)
Apr 1970 -		82	2.04	(1.74, 2.38)
Mar 1971		83	1.73	(1.57, 1.90)
		84	1.71	(1.54, 1.89)
	Greenwich Vil.	85*	2.08	(1.79, 2.43)
May 1970		86	1.34	(1.13, 1.58)
Apr 1971		87	1.22	(1.06, 1.39)
Chicago Urban		60	1.30	(1.17, 1.45)
Mar 1970 -		61	1.35	(1.23, 1.49)
Feb 1971		62	1.53	(1.33, 1.76)
	Bridgeport	63*	1.76	(1.60, 1.93)
		64	1.83	(1.67, 2.02)
		65	1.57	(1.39, 1.78)
		67	1.55	(1.37, 1.76)
		68	1.87	(1.51, 2.31)
Chicago Suburban	Lombard	66*	1.18 (7 mo.)	(0.83, 1.68)
March -				
Sept. 1970				
Houston		50	1.15	(0.92, 1.43)
Mar 1970 -		51	1.02	(0.86, 1.21)
Feb 1971		52	2.13	(1.83, 2.47)
		53	2.26	(1.87, 2.73)
		54	1.32	(1.16, 1.49)
		55	0.87	(0.73, 1.03)
	NW Houston	56*	0.85	(0.75, 0.96)

* blood sampled

Table 5

ANNUAL MEANS OF MONTHLY AVERAGE CONCENTRATIONS OF LEAD AND PARTICULATE MATTER
based on December 61-November 62 and December 68-November 69

Location	Station	Geometric Mean Pb ($\mu g/m^3$) 61-62	Geometric Mean Pb ($\mu g/m^3$) 68-69	% Change (4)/(3)	Confidence Limits for % Change		Geometric Mean PM ($\mu g/m^3$) 61-62	Geometric Mean PM ($\mu g/m^3$) 68-69
(1)	(2)	(3)	(4)	(5)	(6)		(7)	(8)
Los Angeles	1	2.51	4.03	+61**	37	90	121.68	79.35
	2	2.75	4.34	+58**	27	99	105.57	57.72
	3	2.63	3.46	+32**	12	57	112.67	86.77
	4*	2.40	3.72	+55**	36	97	107.71	80.20
	5*	2.04	3.06	+50**	24	80	104.16	79.91
	6	1.48	2.36	+59**	21	107	96.64	57.05
	7	2.17	3.39	+56**	39	76	138.11	83.42
	8	2.80	4.55	+63**	40	88	132.32	80.75
Philadelphia	11	1.39	1.89	+36**	17	56	121.54	97.14
	12	1.75	1.74	- 1	-16	19	117.07	82.00
	13	3.26	3.75	+15	- 2	34	145.07	123.81
	14	2.13	2.18	+ 2	-15	22	124.63	97.78
	15	1.10	1.39	+26**	2	54	83.62	60.29
	16	0.87	1.09	+25**	9	47	68.27	56.11
	17	0.86	1.08	+26**	6	48	78.92	55.97
	18*	-	1.67	-	-	-	-	79.79
	19*	-	1.28	-	-	-	-	64.03
	20*	-	1.01	-	-	-	-	53.84
Cincinnati	30	1.70	1.92	+13	- 5	35	98.14	68.80
	31	1.09	1.45	+33**	6	66	76.31	74.64
	32	1.70	2.13	+25**	7	47	94.12	75.87
	33	0.87	0.85	- 2	-26	28	53.76	56.80
	34*	-	0.31	-	-	-	-	46.07
	35*	-	0.33	-	-	-	-	45.10

* Blood sampled
** Significant at 5% level.

attributed to the lead assay technique. Air flow measurements have been based upon identical procedures during the two test periods. Insofar as can be determined, the sampling and assay procedures during the two periods are directly comparable.

One must consider the possibility that the atmospheric lead levels reported in 1961-62 were inaccurate and too low, a possibility which would tend to show that current levels erroneously reflect a non-existent increase. Evidence for this might rest in the fact that in 1961-62 a number of Los Angeles samples had to be excluded from the site averages. If the excluded samples represented periods of relatively high atmospheric lead levels, the apparent monthly or annual mean lead concentrations at the affected sites would have been too low. Most of the excluded samples had been collected during the photochemical smog season, from June through November. Organic constituents in the air altered the porosity of the filter media in a way which reduced air flow and made volume measurements unreliable. There were times in 1961-62 when only one or two out of eight stations were providing usable data. Special tandem pump units and a reduction in smog levels in 1968-69 eliminated this problem of filter obstruction.

Most of the high-reading samples in 1961-62 in Los Angeles occurred during periods of surface inversions associated with low temperatures rather than during the smog season. The number of lost samples in Los Angeles in 1961-62 approximated 3% of the total filters exposed. While it is possible that the operational situation in Los Angeles in 1961-62 resulted in loss of certain high-reading samples, it is quite unlikely that the losses were of sufficient magnitude to result in the apparent change which is observed in comparison with 1968-69 samples. The problem of filter obstruction never constituted an important problem in other cities.

An examination of meteorological conditions is relevant to the comparison of data collected during the two test periods. Since no meteorological instruments were located at the actual sampling sites, inferences with respect to climatological conditions must be drawn from the data collected by the National Oceanic and Atmospheric Administration (NOAA) at its reference location in each city. These data are valid for precipitation and heating requirements; the data are somewhat less satisfactory for wind velocity and direction but have general validity for the area. That is, wind conditions at the Los Angeles International Airport do not invariably reflect the situation in Pasadena. However, over long periods, such as those used in these studies, local deviations between sampling sites and the NOAA reference station would not be expected to differ to an important degree from year to year. An examination of climatological data during the sampling periods and over a 30-year period does not suggest that either sampling period is non-representative.

That air levels of lead measured in 1961-62 and 68-69 are sufficient to demonstrate a trend at the sampling sites (based upon two points in time) has been questioned. Especially in Los Angeles, the National Air Sampling Network lead data at the reference station show wide annual deviations, upward and downward, over the course of more than ten years (Figure 16). While the results of the study reported here show relatively higher levels of lead in 1968-69 than in 1961-62 at 2 of the 4 Cincinnati sites, at 2 of the 7 Philadelphia sites, and at all of the 8 Los Angeles sites, the NASN data cannot be ignored and deserve further consideration (5)

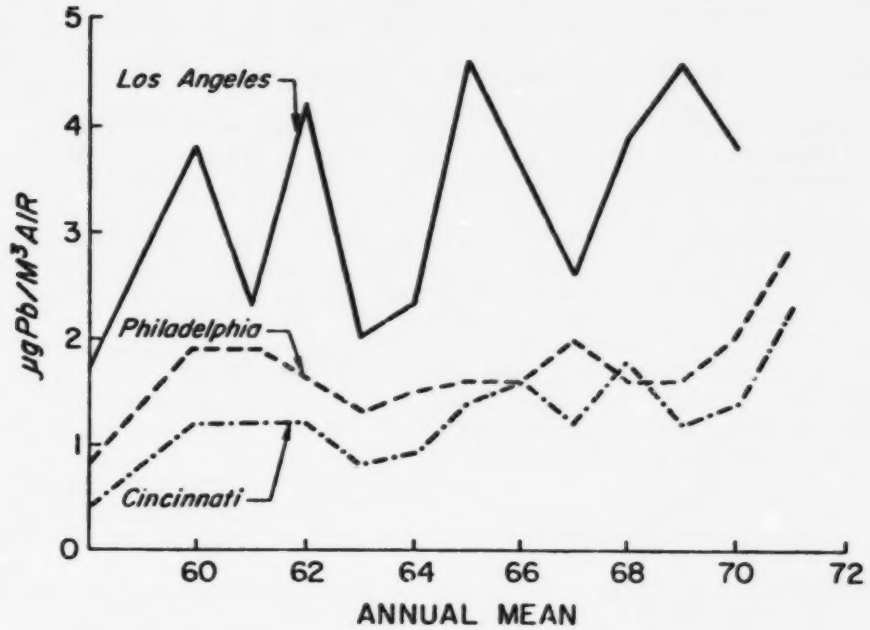


Figure 16. Lead-in-Air Data (1959-71) National Air Sampling Network[5]
(Symbols Indicate 1961-62 and 1968-69 Population and Air Lead Level Studies.)

Note: The Los Angeles NASN site is Station # 1 in this study.
The Philadelphia NASN site is Station # 14 in this study.
The Cincinnati NASN site is Station # 30 in this study.

It is relevant that the NASN system was designed for a less specific purpose, that different collection media and analytical techniques are used, and that the annual mean at each site is based on approximately 26 samples.

Information on atmospheric levels of lead at sites newly established in 1968-71 serves to confirm previous observations which associate higher levels with urban population centers and lower levels with areas of low population densities. Data derived from Okeana (Stations #34,35), Los Alamos (Stations #41,42), and Alpine County reflect an almost "background" situation with respect to atmospheric lead levels.

Month-to-month variations in atmospheric lead levels were generally observed. For the most part highest levels occurred during July-October while the lowest levels occurred in February-April. The variations were most apparent at the Los Angeles sites, where the highest lead levels tended to occur in October-December and the lowest in April-July. Examples of the monthly variations are presented in Figure 17.

Blood Lead Concentrations

Histograms showing the distributions of blood lead concentrations in populations meeting specific epidemiological criteria and living in areas of dissimilar character and atmospheric lead levels are presented in Figure 18. Corresponding frequency distributions are given in Table 6. Mean blood lead values and their 95% confidence limits are presented in Table 7. For epidemiological purposes subjects were excluded from tables and statistical consideration when they:

1) were under 20 or more than 79 years of age;
2) when there appeared to be significant occupational or avocational exposure to lead;
3) when there was a significant amount of wild game in the diet

The inclusion of these subjects in the analyses does not change significantly the computed data means for the several population groups. Appendix 3 presents the blood lead concentrations with no exclusions from the study population.

The age distribution was not consistent for subjects at each area under consideration (Appendix 4). Consequently an age effect might have been apparent in the mean blood lead levels and in their distributions in the various groups. The relationship between age and blood lead levels was examined by means of regression analyses (Table 8). These were carried out for each location separately since patterns of mean levels differed among locations (Figure 19). When a third order model was assumed, the regression of lead on age was shown to be not significant in each location at an overall 5% level. Therefore no adjustment for age has been made in the analyses of blood lead data presented in this report. Mean blood lead levels by age for each location, given in Figure 19, show that there is considerable overlapping of the confidence intervals, supporting the conclusions of non-significant regressions of lead on age.

Since the distribution of persons by cigarette smoking status was not consistent in each location (Appendix 5), and since cigarette smoking was believed to have a possible influence on blood lead levels, tests of the differences in mean blood lead values among locations were carried out after partitioning the sample into three cigarette smoking categories (Tables 9,11,12). The F-ratio testing the differences between the 11 locations is 31,47, which is significant at the 1% level.

Table 9 also shows the influence of smoking upon blood lead levels to be clearly significant ($F = 8.27$). The blood lead level of smokers exceeded that of non-smokers and previous smokers (Tables 11,12). The relationship held true for males as well as females in the husband-wife pairs in Los Alamos (Table 13).

Since the interaction term in Table 9 is not significant ($F = 0.81$), one may conclude that the significant differences among mean blood lead levels in the various locations exist in each smoking category. That is, the average blood lead values of smokers is significantly different among these eleven locations; the same holds true for previous smokers and non-smokers.

Urban-Suburban Blood Lead Levels

The investigation of whether mean blood lead levels reflect degree of urbanization was carried out by applying a binomial test to the data from three metropolitan areas where an urban and suburban population had been sampled. In each location a sample of smokers and non-smokers was used for this test, giving a total of six comparisons between urban and suburban blood lead levels (Table 10a).

In both smoking categories the Philadelphia urban groups ("Rittenhouse") were higher than the suburban ("Ardmore"); the Chicago urban groups ("Bridgeport") were higher that the suburban ("Lombard"); and in New York the urban groups ("Greenwich Village") were higher than the suburban ("Port Washington"). The probability of obtaining 6 relationships in this direction (urban > suburban) out of 6 comparisons is approximately equal to $1/2^6 = 1/64 = 0.015$, if one assumes either direction is to be equally likely. Consequently it is concluded that urban mean

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Figure 17
Atmospheric Lead Levels ($\mu g/m^3$)
by Month for Each Site
(Los Angeles)

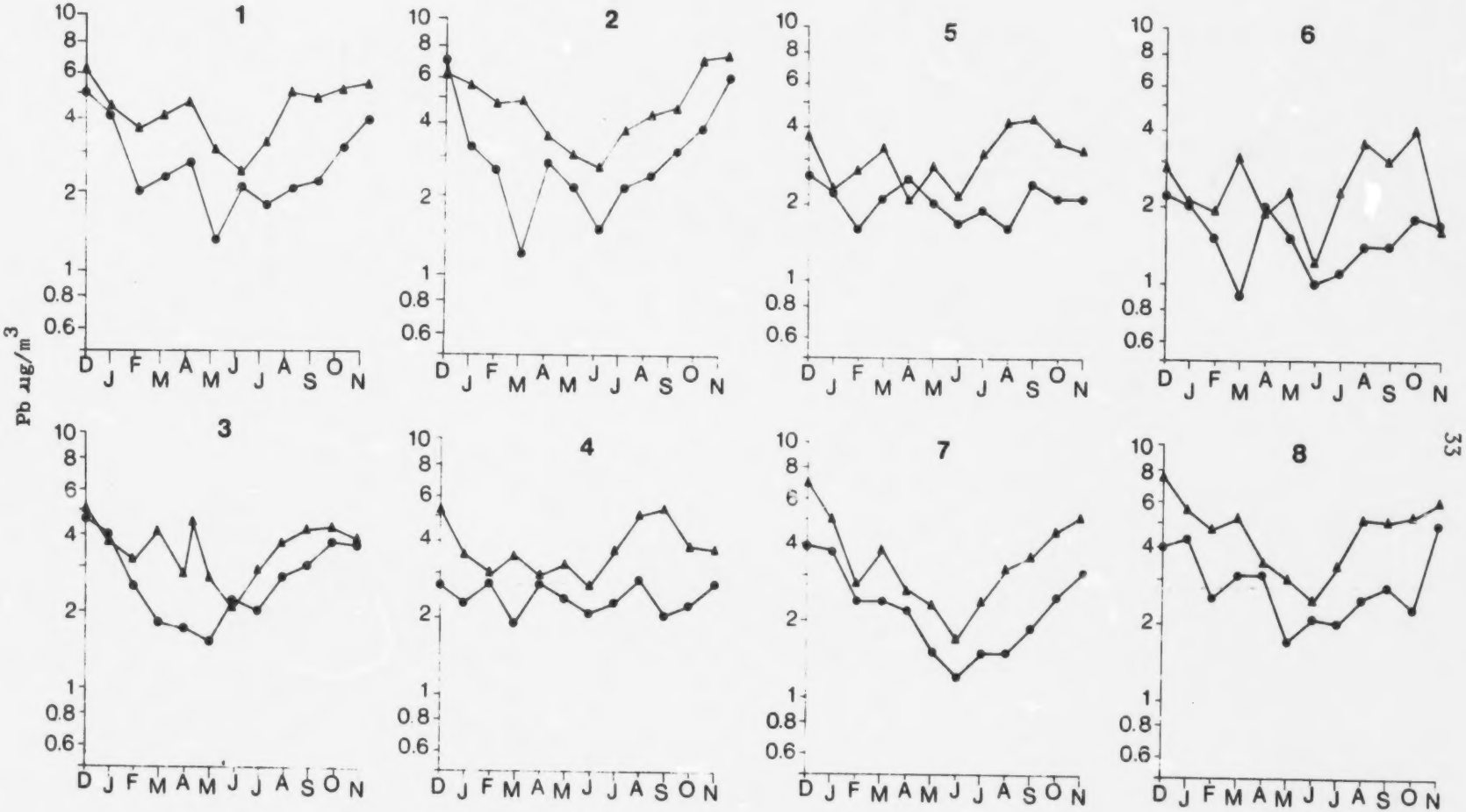


Figure 17 (Continued)

(Philadelphia)

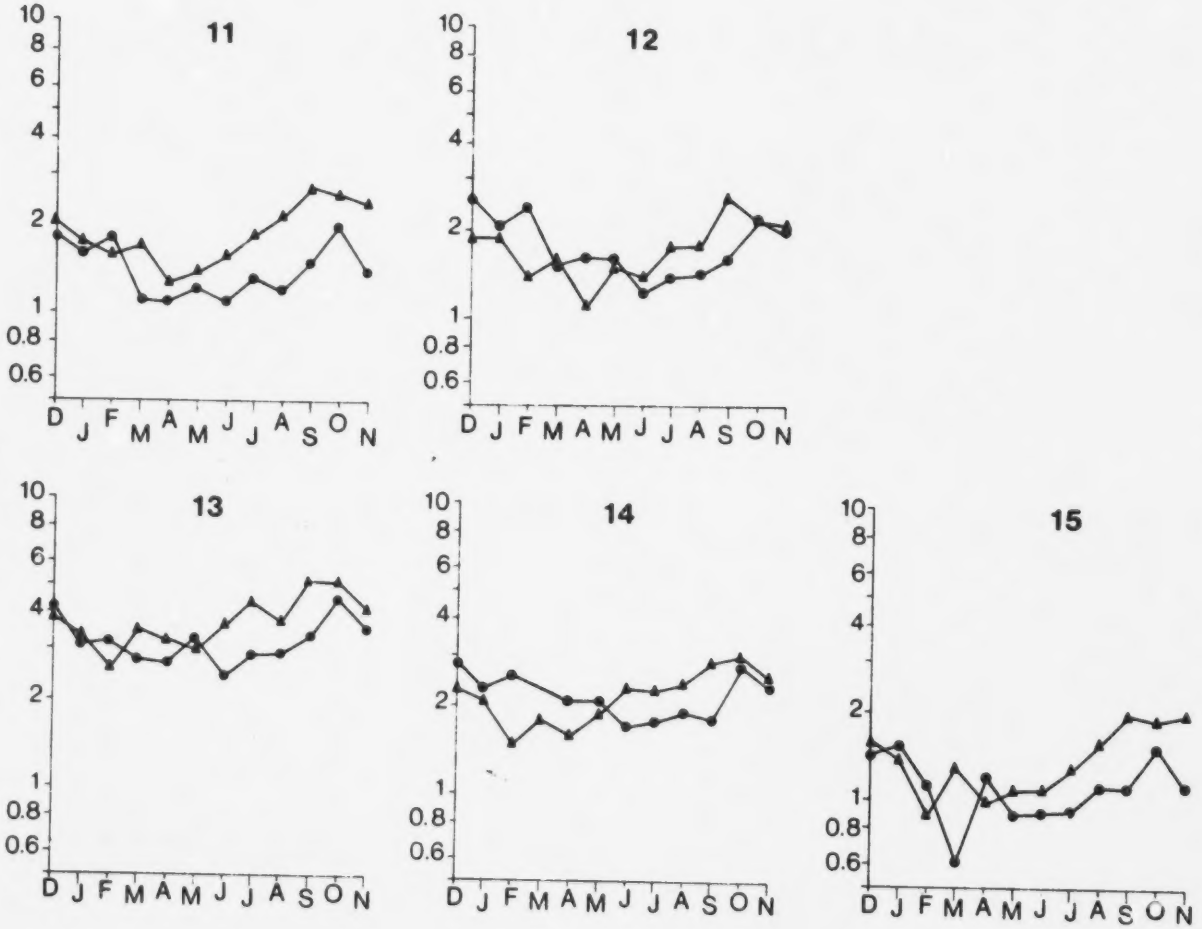
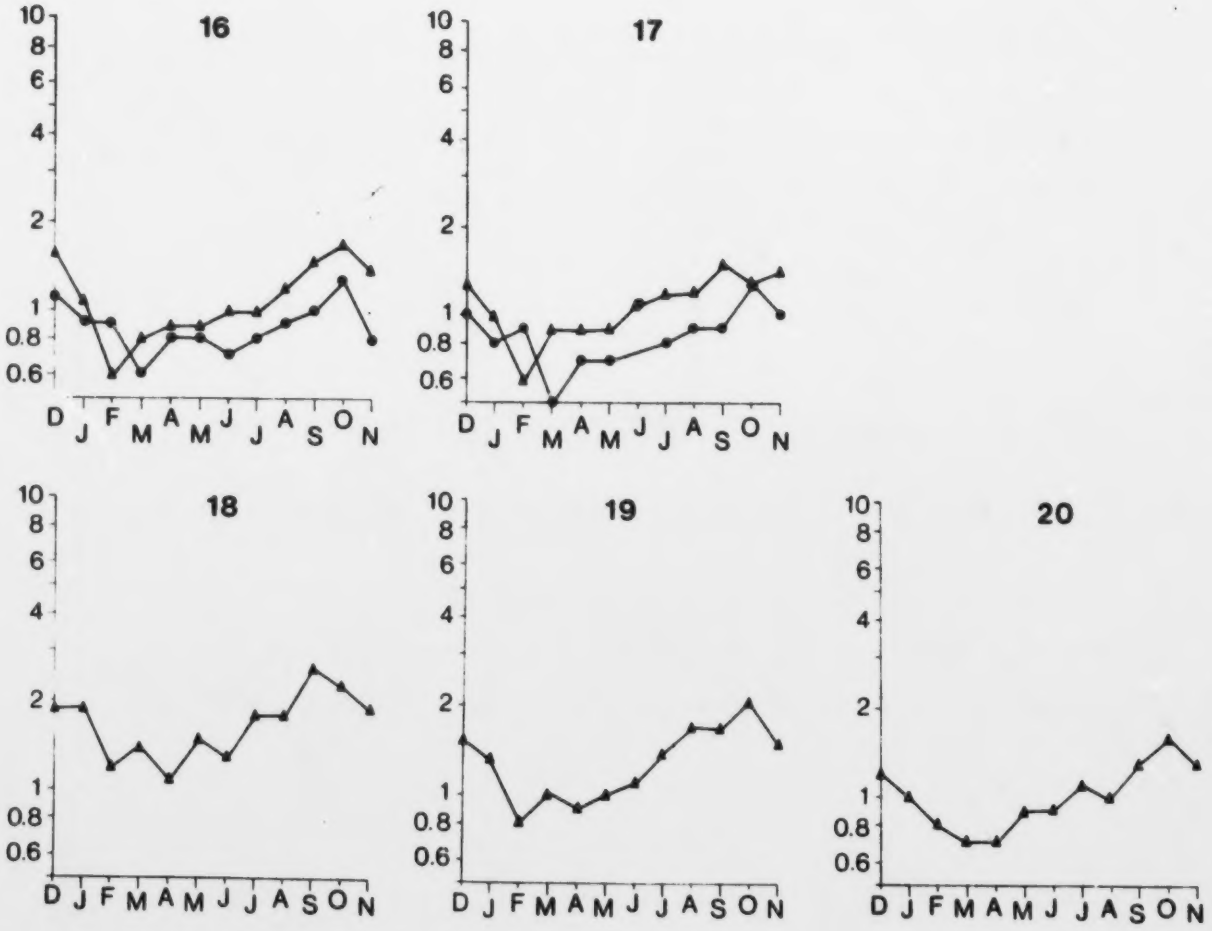


Figure 17 (Continued)

(Philadelphia)

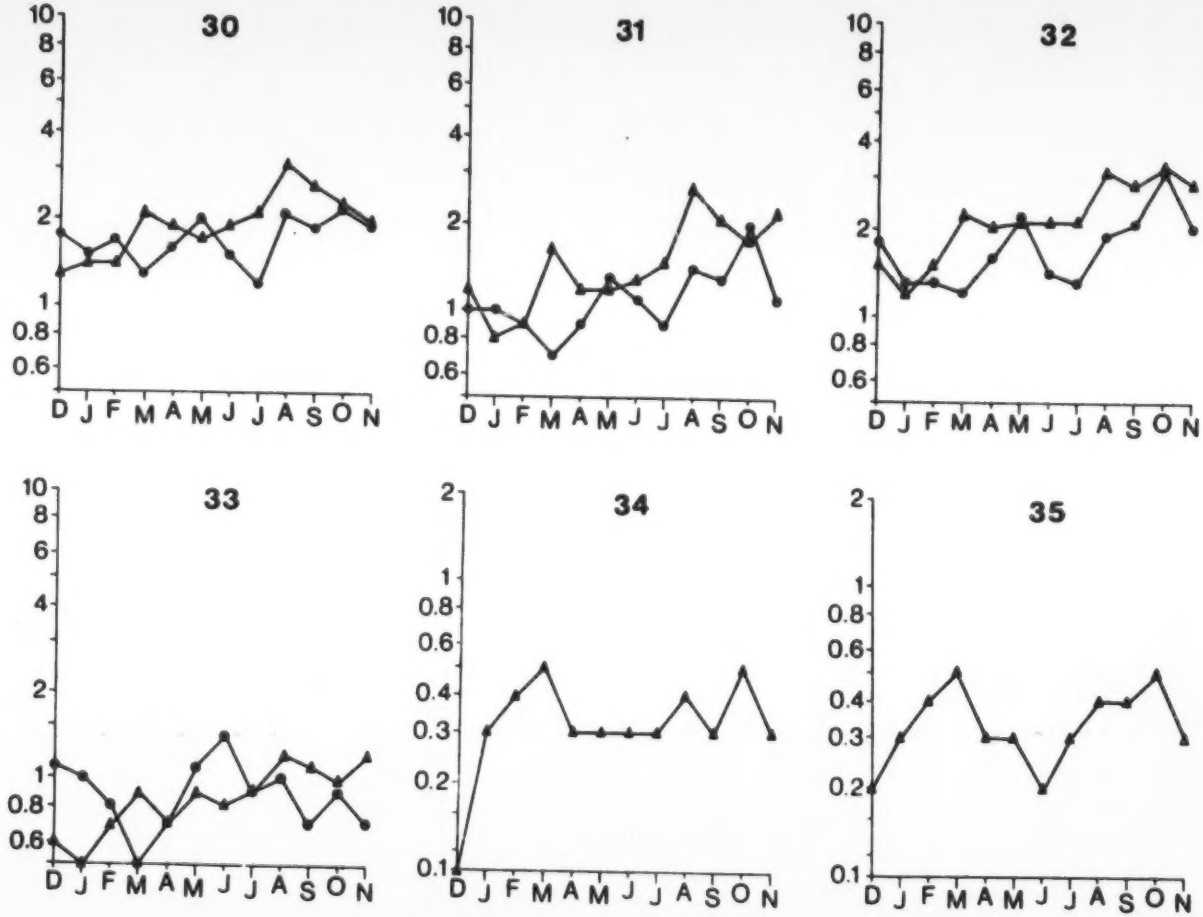


● 1961-62

▲ 1968-69, 70-71

Figure 17 (Continued)

(Cincinnati)

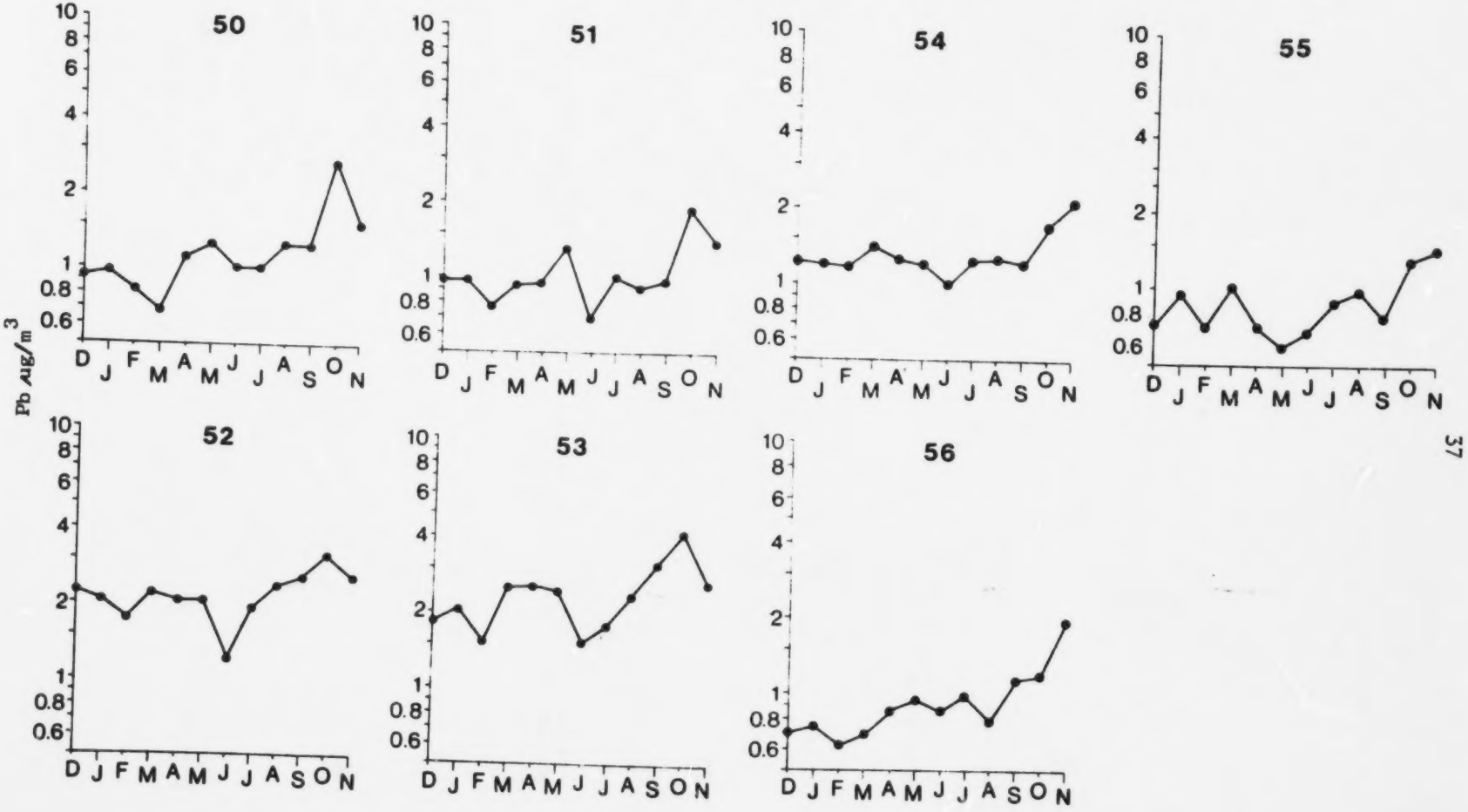


● 1961-62

▲ 1968-69, 70-71

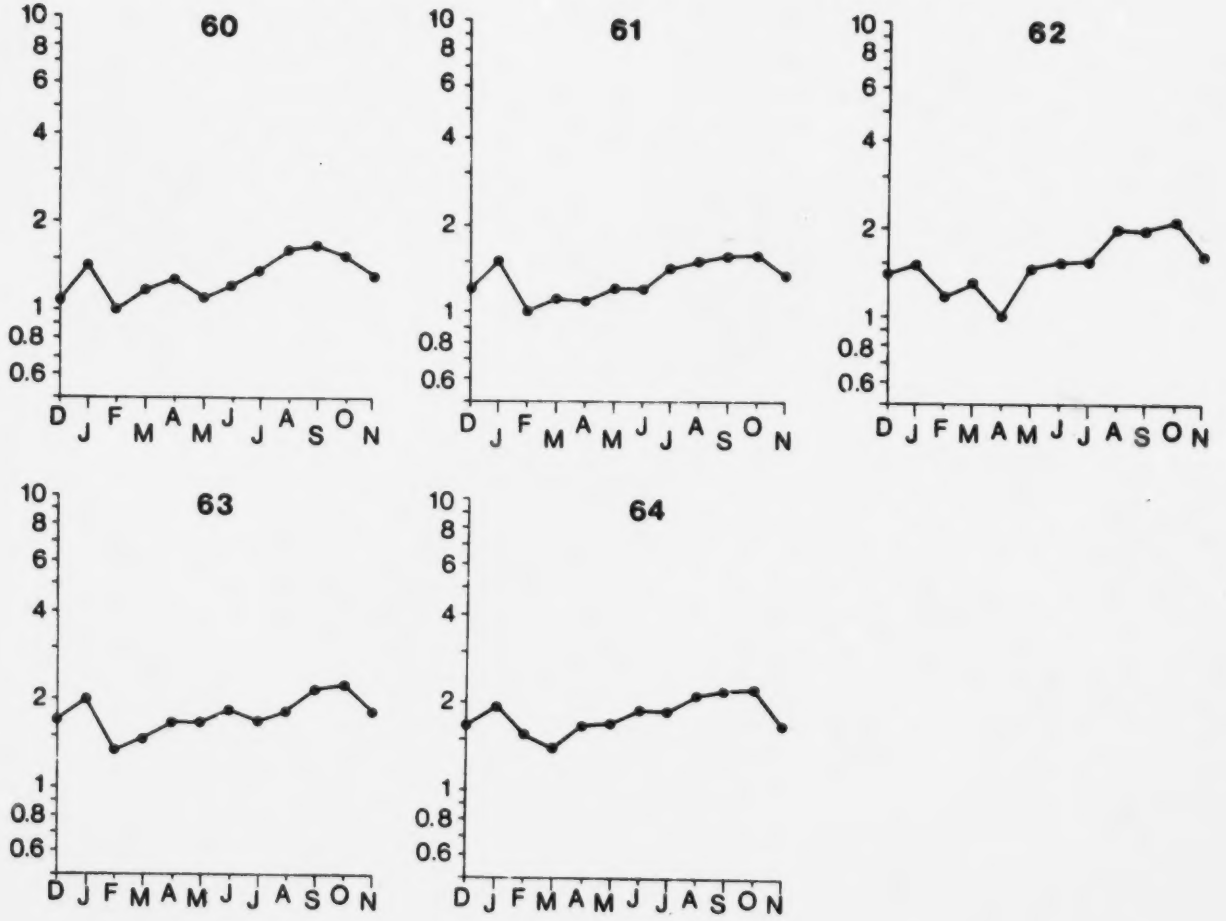
Figure 17 (Continued)

(Houston)



● 1968-69, 70-71

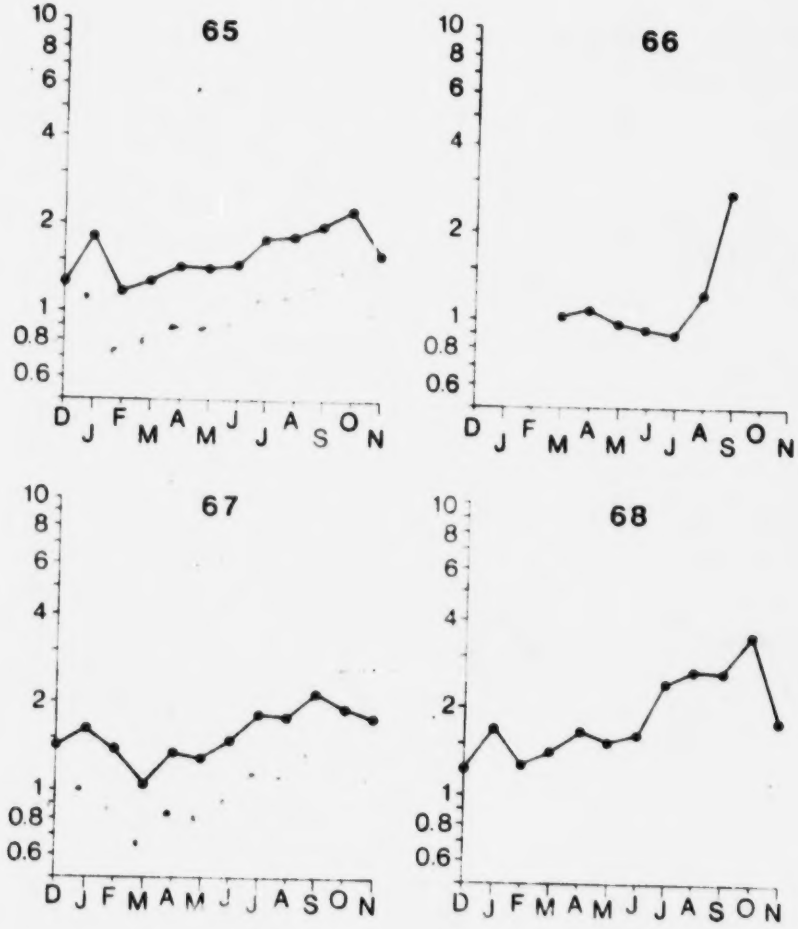
Figure 17 (Continued)
(Chicago)



● 1968-69, 70-71

Figure 17 (Continued)

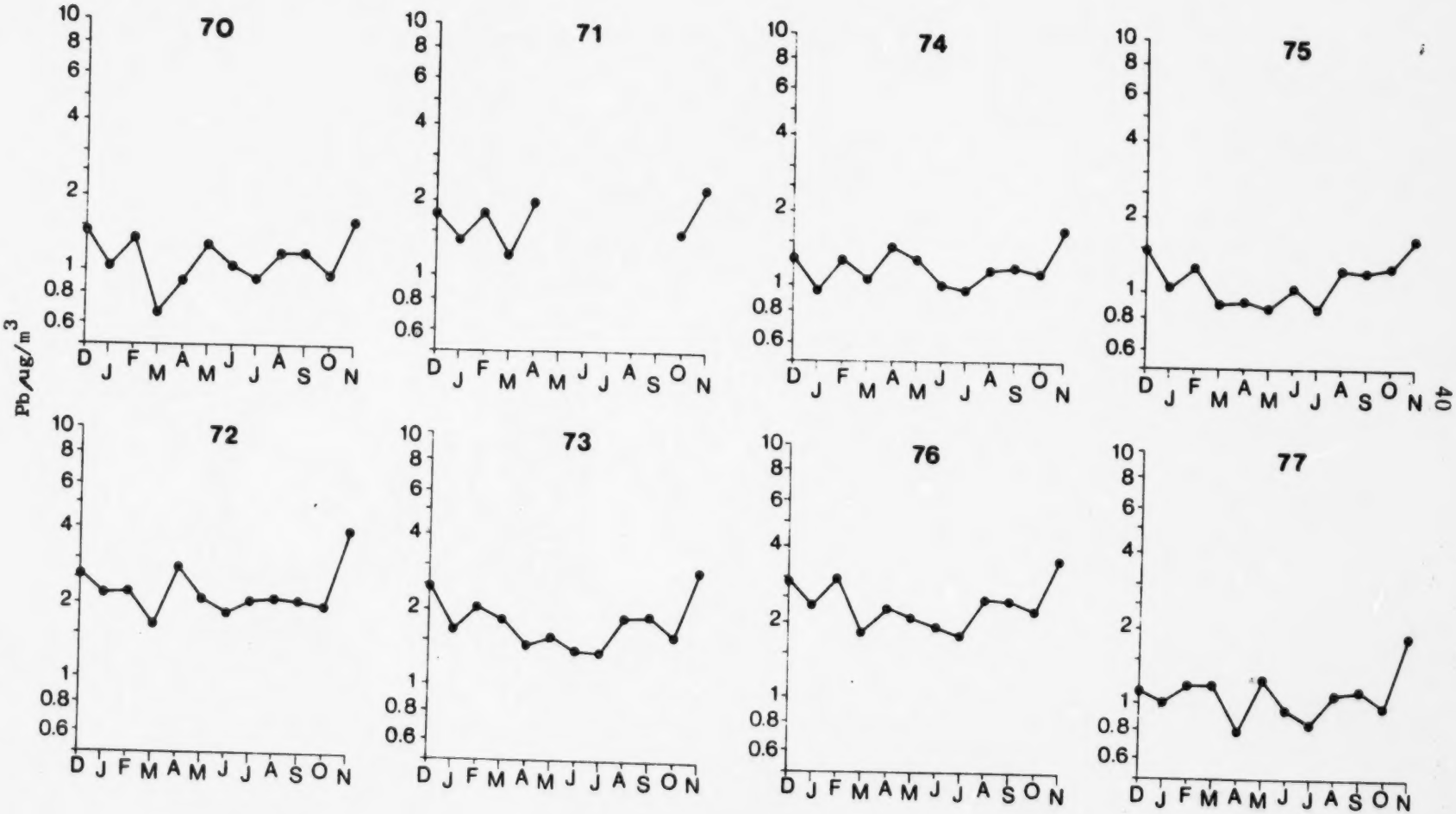
(Chicago)



● 1968-69, 70-71

Figure 17 (Continued)

(Washington)



● 1968-69, 70-71

Figure 17 (Continued)

(New York)

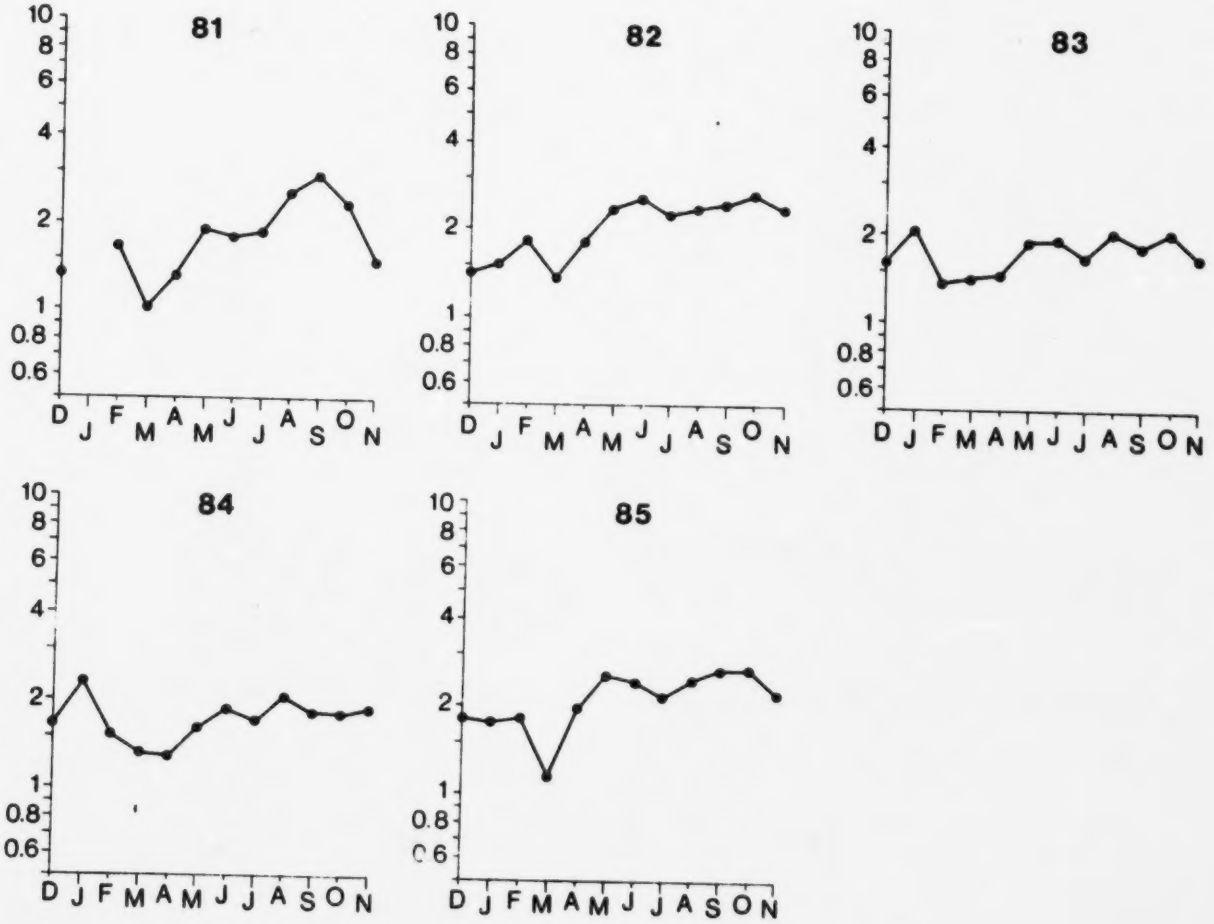
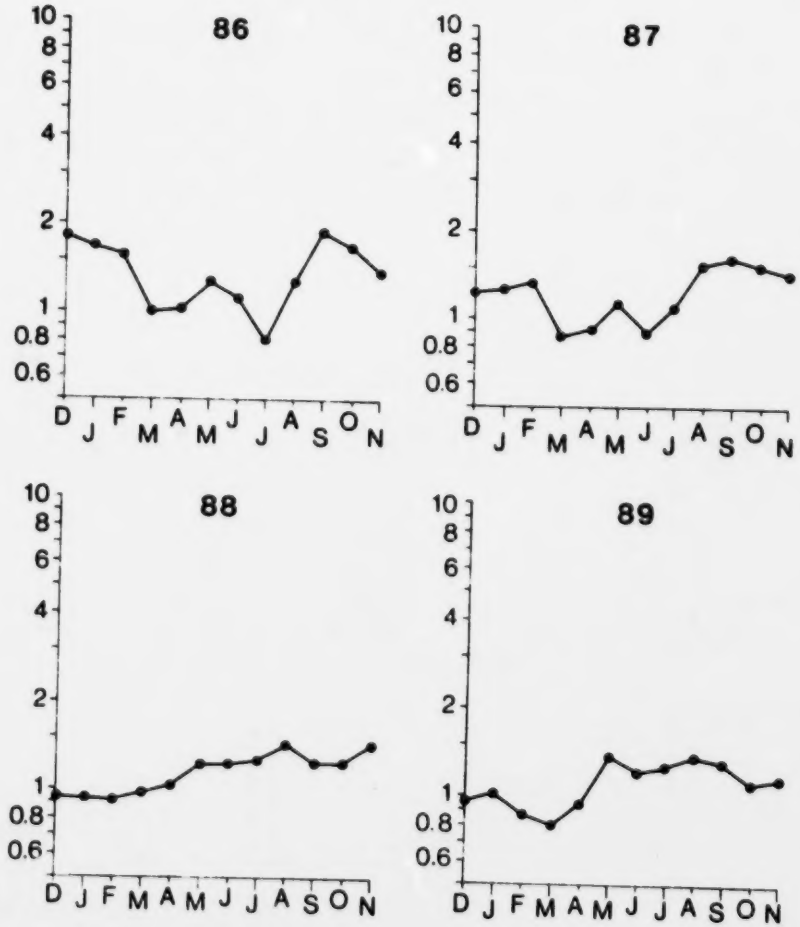


Figure 17 (Continued)

(New York)



● 1968-69, 70-71

Figure 18
Distribution of Blood Lead
Concentrations (µg/100g)

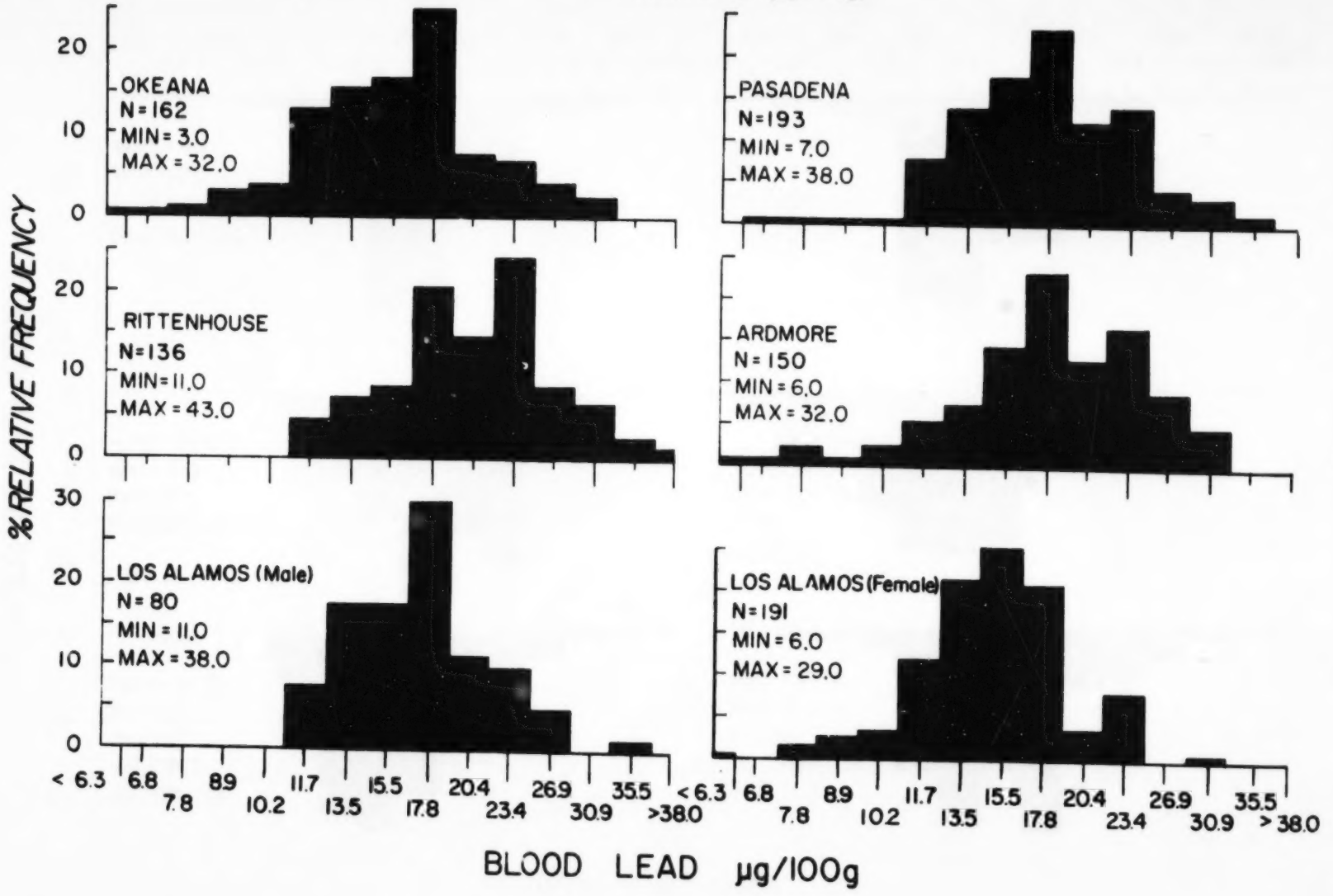


Figure 18 (Continued)

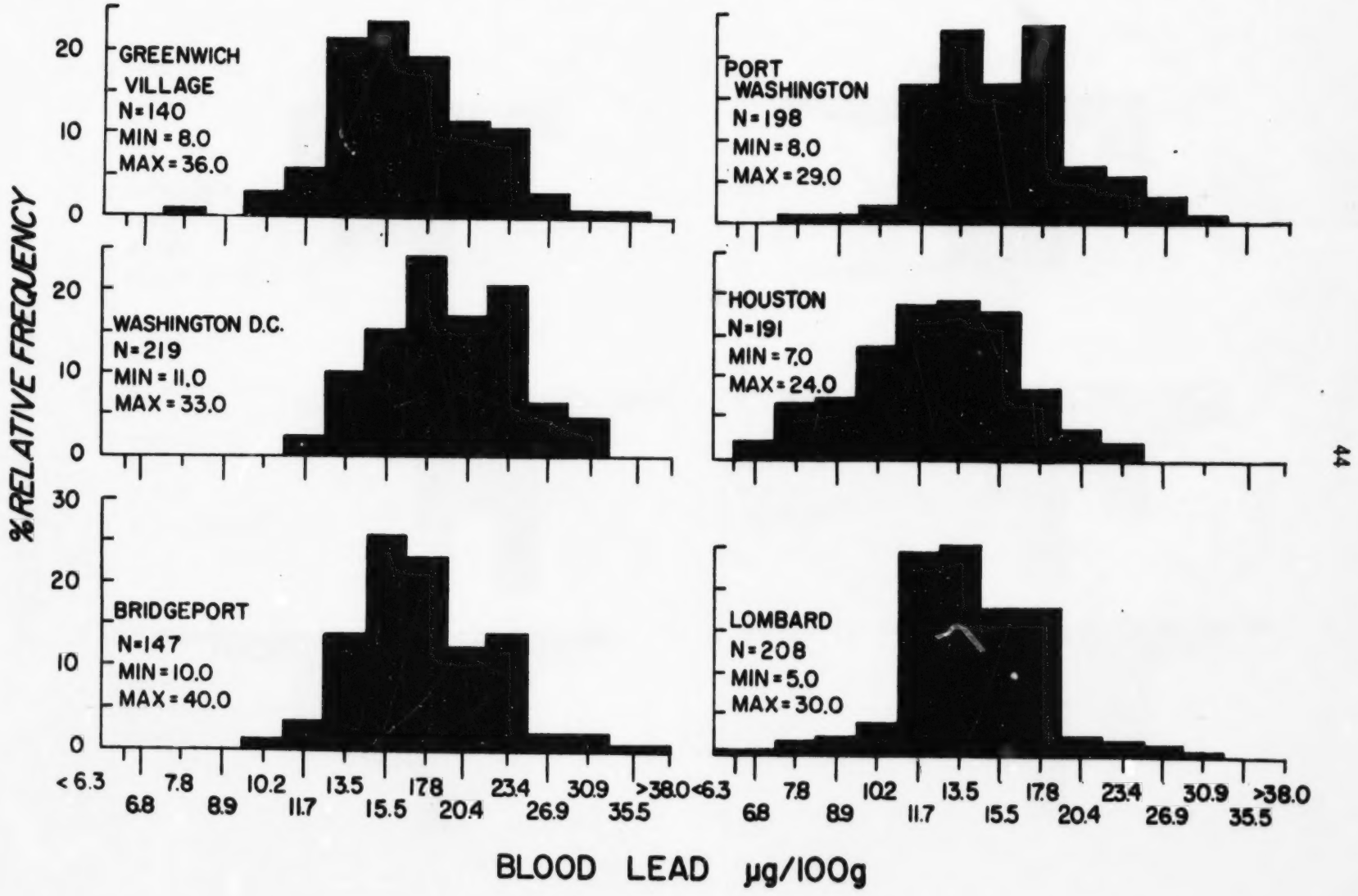


Table 6

Frequency Tables Showing Distribution of Blood Pb Levels in Okeana, Philadelphia, and Pasadena

Log_{10} Pb Interval	Interval Midpoint (µg/100g)	% Relative Frequency			
		Okeana	Ardmore	Rittenhouse	Pasadena
<0.80	<6.8	0.62	0.67	0	0
[0.80-0.86)	6.8	0.62	0.67	0	0.52
[0.86-0.92)	7.8	1.23	2.00	0	0.52
[0.92-0.98)	8.9	3.09	0.67	0	0.52
[0.98-1.04)	10.2	3.70	2.67	0	0.52
[1.04-1.10)	11.7	12.96	5.33	4.41	7.77
[1.10-1.16)	13.5	15.43	7.33	7.35	13.99
[1.16-1.22)	15.5	16.67	14.67	8.82	17.62
[1.22-1.28)	17.8	24.69	23.33	20.59	23.83
[1.28-1.34)	20.4	7.41	12.67	14.71	12.43
[1.34-1.40)	23.4	6.79	16.67	24.26	13.99
[1.40-1.46)	26.9	4.32	8.67	8.82	4.14
[1.46-1.52)	30.9	2.47	4.67	6.62	3.11
[1.52-1.58)	35.5	0	0	2.95	1.04
>1.58	>35.5	0	0	1.47	0
	Min	3.0	6.0	11.0	7.0
	Max	32.0	32.0	43.0	38.0
	N	162	150	136	193

Table 6 (Continued)
Frequency Tables Showing Distribution of Blood Pb Levels in Los Alamos, Washington, D.C., and Port Washington

Log_{10} Pb Interval	Interval Midpoint (µg/100g)	% Relative Frequency			
		Los Alamos (M)	Los Alamos (F)	Washington, D.C.	Port Washington
<0.80	<6.8	0	0.52	0	0
[0.80-0.86)	6.8	0	0	0	0
[0.86-0.92)	7.8	0	1.57	0	1.01
[0.92-0.98)	8.9	0	2.62	0	1.01
[0.98-1.04)	10.2	0	3.14	0	2.02
[1.04-1.10)	11.7	7.50	12.04	2.28	16.67
[1.10-1.16)	13.5	17.50	21.46	10.05	23.23
[1.16-1.22)	15.5	17.50	25.65	15.07	16.67
[1.22-1.28)	17.8	30.00	20.94	24.20	23.74
[1.28-1.34)	20.4	11.25	3.66	16.89	6.57
[1.34-1.40)	23.4	10.00	7.85	20.55	5.55
[1.40-1.46)	26.9	5.00	0	6.39	3.03
[1.46-1.52)	30.9	0	0.52	4.57	0.50
[1.52-1.58)	35.5	1.25	0	0	0
>1.58	>35.5	0	0	0	0
	Min	11.0	6.0	11.0	8.0
	Max	38.0	29.0	33.0	29.0
	N	80.0	191.0	219.0	198.0

Table 6 (Continued)
Frequency Tables Showing Distribution of Blood Pb Levels in Greenwich Village, Chicago, and Houston

% Relative Frequency

$\log_{10}$ Pb Interval	Interval Midpoint (µg/100g)	Greenwich Village	Lombard	Bridgeport	Houston
<0.80	<6.8	0	0.48	0	0
[0.80-0.86)	6.8	0	0.48	0	2.09
[0.86-0.92)	7.8	0.71	1.44	0	6.80
[0.92-0.98)	8.9	0	1.92	0	7.32
[0.98-1.04)	10.2	2.86	3.84	1.36	13.61
[1.04-1.10)	11.7	5.71	24.51	3.40	18.84
[1.10-1.16)	13.5	21.43	25.48	13.60	19.37
[1.16-1.22)	15.5	23.58	17.78	26.53	17.80
[1.22-1.28)	17.8	19.28	17.78	23.12	8.37
[1.28-1.34)	20.4	11.43	2.40	12.24	3.66
[1.34-1.40)	23.4	10.71	1.92	14.28	2.09
[1.40-1.46)	26.9	2.86	1.44	2.04	0
[1.46-1.52)	30.9	0.71	0.48	2.04	0
[1.52-1.58)	35.5	0.71	0	0.68	0
≥1.58	>35.5	0	0	0.68	0
	Min	8.0	5.0	10.0	7.0
	Max	36.0	30.0	40.0	24.0
	N	140	208	147	191

Table 7

Geometric Means and Confidence Intervals of
Blood Lead Levels Based on a
Single Determination from Each Subject

(Rank)	Area	N	Geometric Mean (mg/100g)	95% Confidence Limits (mg/100g)
5	Okeana	162	0.0157	(0.0150, 0.0165)
9	Ardmore	150	0.0180	(0.0171, 0.0190)
11	Rittenhouse	136	0.0205	(0.0196, 0.0215)
7	Pasadena	193	0.0175	(0.0169, 0.0182)
3	Los Alamos (-)	191	0.0149	(0.0144, 0.0155)
10	Washington, D.C.	219	0.0192	(0.0186, 0.0198)
4	Port Washington	198	0.0153	(0.0148, 0.0159)
6	Greenwich Village	140	0.0166	(0.0159, 0.0173)
2	Lombard	208	0.0139	(0.0135, 0.0144)
8	Bridgeport	147	0.0176	(0.0169. 0.0183)
1	Houston	191	0.0125	(0.0120, 0.0130)
	All Females	1935	0.0162	(0.0160, 0.0164)
	Los Alamos (M)	80	0.0172	(0.0163, 0.0182)

blood lead levels are significantly higher than those from related suburban areas (at the 1.5% level), based on data from three paired locations in Philadelphia, New York, and Chicago.

Tests of the differences in blood lead levels in urban and suburban populations of smokers only and of non-smokers only for each location separately (i.e., Philadelphia, New York, and Chicago) were carried out by calculating F-ratios for the comparisons. The significance tests are made by comparing these F-ratios to the critical values specified by the appropriate statistical test. On the basis of the judgment that the Tukey statistical test is most appropriate to the situation under examination, it is inferred that a significant urban-suburban gradient for both smokers and non-smokers exists in the Philadelphia and Chicago areas. The differential in the New York area was not shown to be clearly significant.

The relationship between mean blood lead levels and degree of urbanization was also investigated by testing the significance of F-ratios obtained when the urban and suburban mean blood lead levels were compared in each of three locations. Based on the total sample (smokers, non-smokers, previous smokers), the urban mean lead value is higher than the suburban in each location and all locations combined on the basis of the Tukey test (Table 10b).

Table 14 and Figure 20 present mean blood lead levels and corresponding mean air lead levels at the sites where both were measured. The association between these mean values was measured by means of the Pearson Product Moment Correlation Coefficient and Kendall's Rank Correlation Coefficient. The values obtained were 0.412 and 0.354, respectively, for all data. Corresponding values for non-smokers only were 0.400 and 0.345. These values were not significant at the 5% level. It was therefore concluded that the data do not contradict the hypothesis of no association between average blood and air lead concentrations under the total environmental circumstances which exist at the study locations.

The observations that urban levels of blood lead are significantly higher than suburban levels, but that air concentration of lead are not clearly reflected in blood lead levels generally, suggest that other variables are more important than ambient air lead levels in determining concentrations of lead in the blood. The precise nature of the variables, which evidently differ in the several regions studied, remains undefined. Presumably alimentary lead intake plays a significant role; however this was not thoroughly evaluated in the short-term metabolic study. Climatic factors may also be relevant.

In a given metropolitan area, urban-suburban comparisons tend to minimize the influence of diet and climate. That airborne lead contributes to the relatively higher blood lead concentrations in center-city populations would seem to be the most probable interpretation of this consistent observation.

Mention should be made of the possibility that persons who live primarily indoors, as do the population groups in this study, are exposed to air levels of lead which differ from those which exist in the ambient outside neighborhood atmosphere. While this is very probably the case, it is likely that the ratio between indoor and outdoor air lead concentrations is similar in different communities. Consequently indoor exposures are directly related to lead levels

Text continued on page 60

Table 8

Analyses of Functional Relationship Between Blood Lead and Age for Non-Smokers

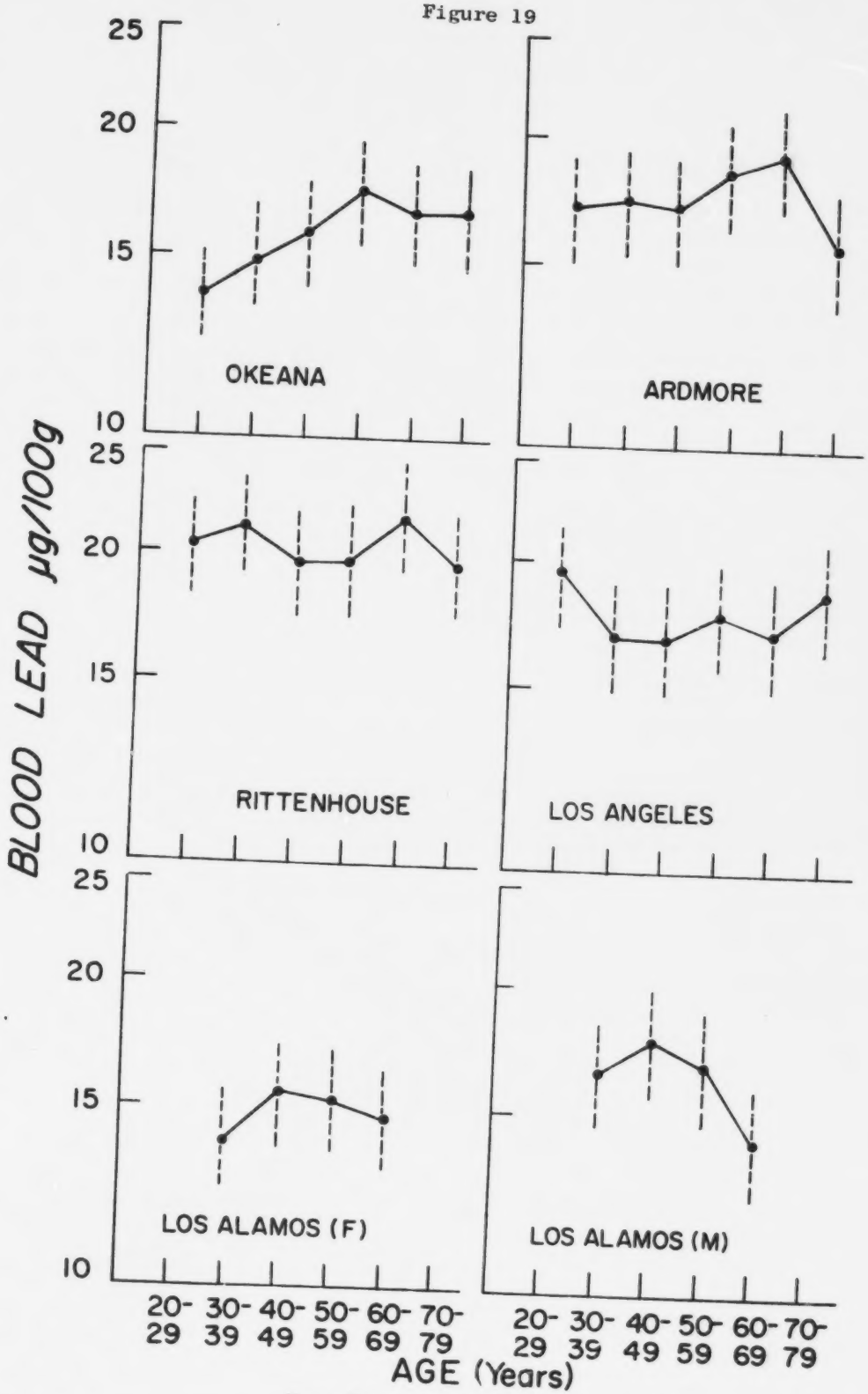
	Source of Variation	df	SS	MS	F
Okeana N = 131	Due to regression	3	0.1346	0.0448	2.19 (NS)
	About regression	127	2.6019	0.0205	
	Error	125	2.5953	0.0210	
	Lack of fit	2	0.0066	0.0033	0.16
Ardmore N = 99	Due to regression	3	0.1653	0.0551	2.93 (NS)
	About regression	95	1.7854	0.0188	
	Error	93	1.7795	0.0190	
	Lack of fit	2	0.0059	0.0029	0.15
Rittenhouse N = 76	Due to regression	3	0.0413	0.0138	1.03 (NS)
	About regression	72	0.9678	0.0134	
	Error	70	0.9487	0.0140	
	Lack of fit	2	0.0191	0.0096	0.69
Pasadena N = 134	Due to regression	3	0.1072	0.0357	2.30 (NS)
	About regression	130	2.0087	0.0155	
	Error	128	1.9656	0.0150	
	Lack of fit	2	0.0431	0.0215	1.43
Los Alamos (F) N = 106	Due to regression	3	0.0907	0.0302	2.40 (NS)
	About regression	102	1.2900	0.0126	
	Error	102	1.2900	0.0126	
	Lack of fit	-	-	-	
Washington, D C. N = 105	Due to regression	3	0.0210	0.0070	0.71 (NS)
	About regression	101	0.9962	0 0099	
	Error	99	0.9909	0.0100	
	Lack of fit	2	0.0053	0.0027	0.27
Port Washington N = 87	Due to regression	3	0.0454	0.0151	1.12 (NS)
	About regression	83	1.1190	0.0135	
	Error	81	1.0573	0.0130	
	Lack of fit	2	0.0617	0.0309	2.38
Greenwich Village N = 56	Due to regression	3	0.0004	0.0001	0.01 (NS)
	About regression	52	0.6132	0.0118	
	Error	50	0.6088	0.0120	
	Lack of fit	2	0.0044	0.0022	0.18

(NS) Setting a 5% significance level for testing the significance of regression on age for all locations, we must use a 0.5% significance level in each individual location. The critical valuefor this test is equal to 4.28. (df=3,∞).

	Source of Variation	df	SS	MS	F
Lombard N = 125	Due to regression	3	0.0029	0.0009	0.08 (NS)
	About regression	121	1.3071	0.0108	
	Error	119	1.2793	0.0110	
	Lack of fit	2	0.0278	0.0139	1.26
Bridgeport N = 85	Due to regression	3	0.0353	0.0117	1.36 (NS)
	About regression	81	0.6980	0.0086	
	Error	79	0.6557	0.0080	
	Lack of fit	2	0.0423	0.0211	2.64
Houston N = 123	Due to regression	3	0.0286	0.0095	0.76 (NS)
	About regression	119	1.4867	0.0125	
	Error	117	1.4756	0.0130	
	Lack of fit	2	0.0111	0.0056	0.43
Los Alamos (M) N = 32	Due to regression	3	0.0443	0.0147	0.95 (NS)
	About regression	28	0.4348	0.0155	
	Error	28	0.4348	0.0155	
	Lack of fit	-	-	-	

(NS) Setting a 5% significance level for testing the significance of regression on age for all locations, we must use a 0.5% significance level in each individual location. The critical value for this test is equal to 4.28. ($df=3,\infty$).

Figure 19



Mean Blood Lead Levels (ug/100g)
and 95% Confidence Limits by Age

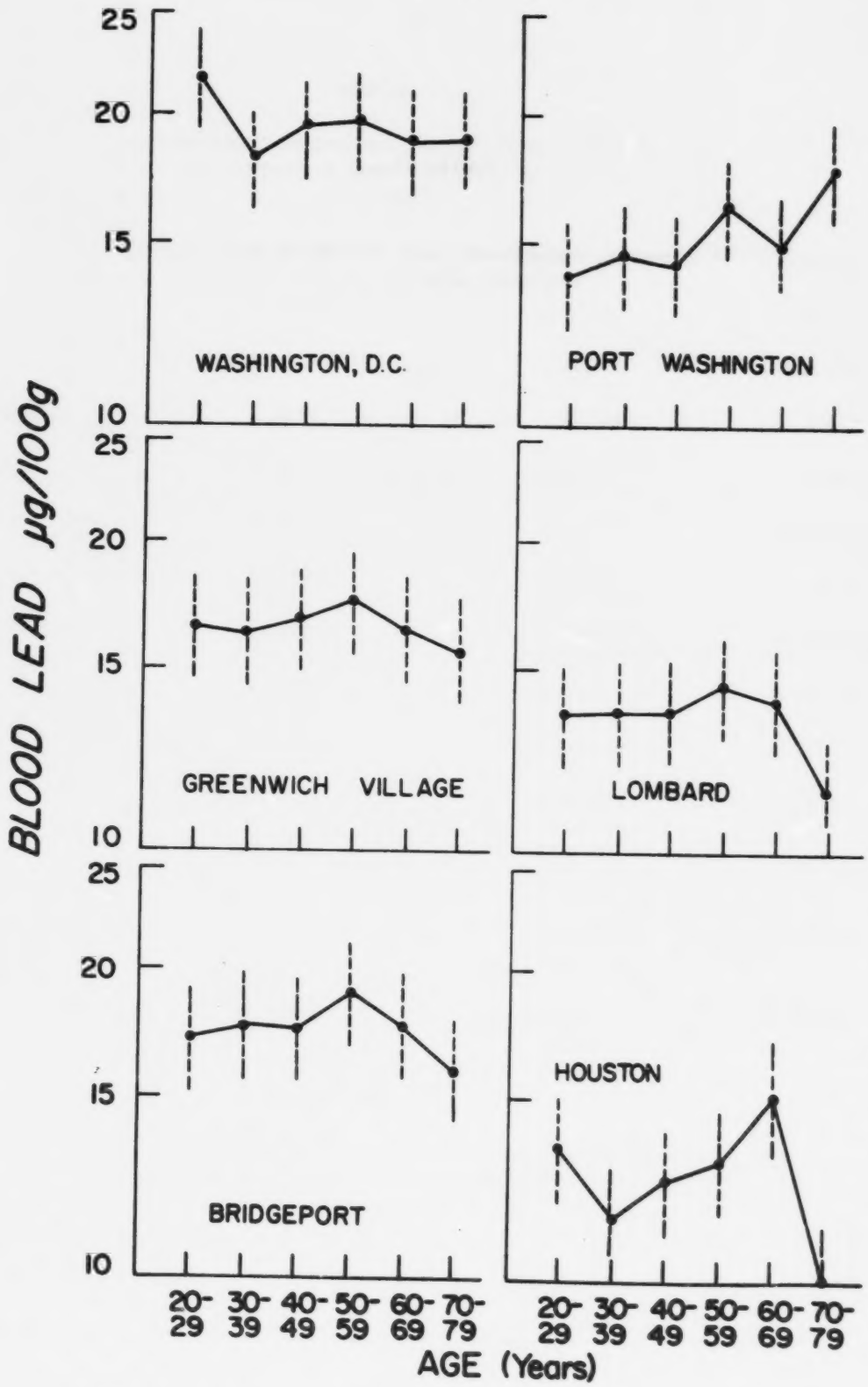


Figure 19 (Continued)

Table 9

Analysis of Variation Due to Smoking Status (Females) and Location

Source	df	SS	MS	F
Smoking	2	0.2167	0.1083	8.27**
Location	10	4.1244	0.4124	31.47**
Interaction	20	0.2120	0.0106	0.81
Error	1893	24.8060	0.0131	

** Significant at the 1% level.

Table 10a

Relationship Between Mean Blood Lead Levels
and Degree of Urbanization in Paired Locations

Smokers

Comparison	F-ratio	Direction
Rittenhouse vs Ardmore (N=40) (N=29)	6.65*	Urban > Suburban
Greenwich Village vs Port Washington (N=47) (N=69)	1.67	Urban > Suburban
Bridgeport vs Lombard (N=54 (N=99)	26.09*	Urban > Suburban

Non-Smokers

Rittenhouse vs Ardmore (N=77) (N=99)	8.29*	Urban > Suburban
Greenwich Village vs Port Washington (N=56) (N=87)	1.31	Urban > Suburban
Bridgeport vs Lombard (N=85) (N=125)	31.77*	Urban > Suburban

Table 10b

F-Ratios Testing the Difference Between Urban and Suburban
Lead Levels in the Total Sample (Including Previous Smokers)

	F-ratio	
Rittenhouse vs Ardmore (N=133) (N=150)	18.18*	Urban > Suburban
Greenwich Village vs Port Washington (N=139) (N=197)	5.98*	Urban > Suburban
Bridgeport vs Lombard (N=146) (N=207)	65.43*	Urban > Suburban
Total: Urban vs Suburban (based on Philadelphia, New York, and Chicago)	71.56*	Urban > Suburban

*Significant at the 5% level (Tukey Test)

Note: Critical Values (5%) for Judging Significance
of Comparisons in Tables 10a and 10b

"Standard" F	Tukey Critical Value	Scheffé Critical Value
3.84	4.55	18.30

Table 11

GEOMETRIC MEANS OF BLOOD LEAD LEVELS
BY LOCATION AND SMOKING STATUS
(mg/100g)

	Non-Smokers	Previous Smokers	Smokers
Okeana	0.0156	0.0139	0.0171
Ardmore	0.0180	0.0177	0.0181
Rittenhouse	0.0202	0.0200	0.0214
Pasadena	0.0172	0.0179	0.0183
Los Alamos (F)	0.0144	0.0154	0.0160
Washington D. C.	0.0181	0.0205	0.0201
Port Washington	0.0149	0.0150	0.0162
Greenwich Village	0.0158	0.0167	0.0173
Lombard	0.0136	0.0146	0.0146
Bridgeport	0.0167	0.0166	0.0191
Houston	0.0126	0.0120	0.0124
All Females	0.0158 (1127)	0.0162 (304)	0.0173 (495)
Los Alamos (M)	0.0165	0.0168	0.0193

Table 12

Further Analyses of Relationship Between
Blood Lead and Smoking Status

Comparison	F	Direction
Smokers vs. Non-Smokers	40.01**	Smokers > Non-Smokers
Smokers vs. Prev. Smokers	10.37**	Smokers > Prev. Smokers
Prev. Smokers vs. Non-Smokers	2.57	Prev. Smokers > Non-Smokers

** Significant at the 1% level.

Table 13

Geometric Means of Blood Lead Levels for Los Alamos Males and Females by Smoking Status

	Non-Smokers	Previous Smokers	Smokers	All
Los Alamos (F)	0.0144	0.0154	0.0160	0.0149 (191)
Los Alamos (M)	0.0165	0.0168	0.0193	0.0172 (80)

Analysis of Variation due to Sex (Los Alamos data)

Source	df	SS	MS	F
Sex	1	0.1822	0.1822	16.30**
Smoking Status	2	0.1093	0.0546	4.89**
Interaction	2	0.0167	0.0084	0.75
Error	263	2.9402	0.0112	

Correlation Coefficients between Los Alamos Couples

Smoking Status	No. Couples	Correlation Coefficient (95% Confidence Interval)
Same	36	0.353* (0.027, 0.610)
Differing	43	0.265 (NS) (-0.038, 0.581)

* Significant at 5% level.
**Significant at 1% level.

Table 14

Air and Blood Lead Concentrations (1968-71)
(All Subjects)

Air Rank	Area	Geometric Means Air ($\mu g/m^3$)	Geometric Means Blood (mg/100g.)	Blood Rank
1	Los Alamos	0.17	0.0149 (F)	3
2	Okeana	0.32	0.0157	5
3	Houston	0.85	0.0125	1
4	Port Washington	1.13	0.0153	4
5	Ardmore	1.15	0.0180	9
6	Lombard	1.18 (7 mo.)	0.0139	2
7	Washington, D.C.	1.19	0.0192	10
8	Rittenhouse	1.67	0.0205	11
9	Bridgeport	1.76	0.0176	8
10	Greenwich Village	2.08	0.0166	6
11	Pasadena	3.39	0.0175	7

Relationship Between Means of Air and Blood Lead (Females)
Based on Pearson Product Moment Correlation Coefficient (r)
and Kendall's Rank Correlation Coefficient (τ)

$r = 0.412$ (NS)

$\tau = 0.354$ (NS)

(F) Females
(NS) Not significantly different from 0 at the 5% level.

Table 15

Air and Blood Lead Concentrations (1968-71)
(Non-Smokers Only)

Air Rank	Area	Geometric Means: Air ($\mu g/m^3$)	Geometric Means: Blood (mg/100g.)	Blood Rank
1	Los Alamos	0.17	0.0144 (F)	3
2	Okeana	0.32	0.0156	5
3	Houston	0.85	0.0126	1
4	Port Washington	1.13	0.0149	4
5	Ardmore	1.15	0.0180	9
6	Lombard	1.18 (7 mo.)	0.0136	2
7	Washington, D.C.	1.19	0.0181	10
8	Rittenhouse	1.67	0.0202	11
9	Bridgeport	1.76	0.0167	7
10	Greenwich Village	2.08	0.0158	6
11	Pasadena	3.39	0.0172	8

Relationship Between Means of Air and Blood Lead (Females)
Based on Pearson Product Moment Correlation Coefficient (r)
and Kendall's Rank Correlation Coefficient (τ)

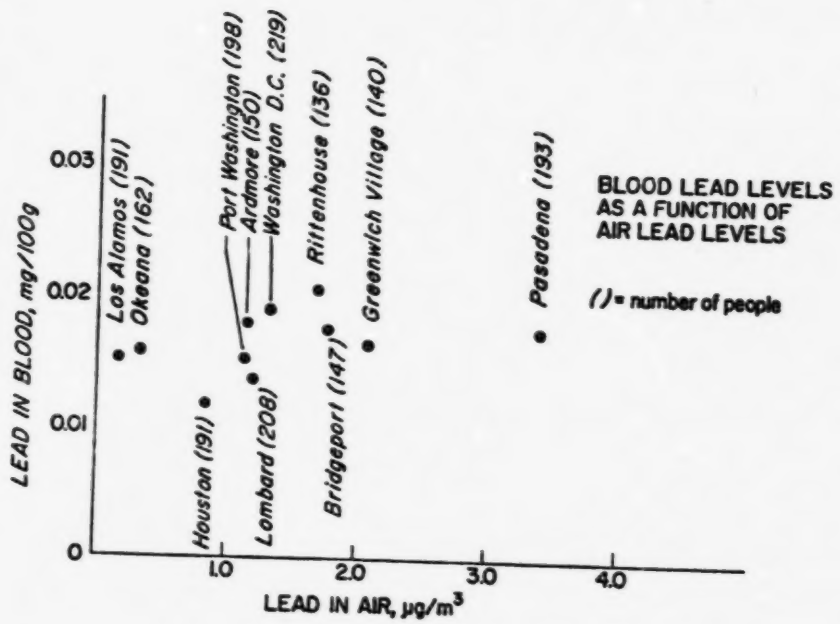
$r = 0.400$ (NS)

$\tau = 0.345$ (NS)

(F) Females
(NS) Not significantly different from 0 at the 5% level.

measured outdoors. It is not immediately apparent that certain groups spend relatively greater amounts of time outdoors. If this point were significant, presumably the Pasadena population would experience relatively greater outdoor exposure. Accordingly we do not feel that a consideration of indoor-outdoor time or air conditioning alters the principal inferences drawn from this study.

Figure 20
Blood Lead Levels and Corresponding
Mean Air Lead Levels



Male-Female Blood Lead Differentials

The examination of blood lead levels in husband-wife pairs in Los Alamos revealed a significant difference between males and females (Table 13). The basis for this difference remains to be established. We believe that it cannot be attributed to occupational factors, for the work of each individual was characterized and conducted under comprehensive and detailed industrial hygiene supervision. It is generally true that men smoke more than do women; however, the blood lead levels in males remained higher than in female smokers and non-smokers.

Since men have generally higher hematocrit levels than do women and since lead is transported in association with red blood cells, the possibility exists that higher blood lead concentrations in men reflect a higher level of circulating red cells. An associated question related to whether or not relatively higher hematocrits in women of Los Alamos (elevation: 7,300 feet) might be responsible for their blood lead levels being higher than would be the case at sea

level. The anticipated gradient in hematocrits, Los Alamos males > Los Alamos females > Pasadena females, was observed (Table 16). The analysis of variance testing the significance of the difference among the hematocrit values of these three groups was significant at the 1% level ($F = 80.26$). The comparison between Pasadena and Los Alamos females also was significant at the 1% level, ($F = 11.54$), the mean value of Los Alamos females being higher than that of Pasadena females.

The functional relationship between blood lead and hematocrit level was examined within each of the three groups separately (non-smokers only) to see if an "adjustment" could be made in the blood lead values which would make it possible to obtain better comparisons among the three groups (Table 16). In Los Alamos, the regressions were not significant; therefore it was concluded that no significant association between blood lead determinations and hematocrit values could be found among Los Alamos males or females. In Pasadena a significant second-order regression was found which is difficult to interpret as far as the effect on blood lead values is concerned. For this reason no "adjustment" for hematocrit level was made on the blood lead values of this area.

Since the mean blood lead value for Los Alamos is lower than that of Pasadena and since there was no significant (linear) correlation between blood lead and hematocrit level, the relative size of the mean blood lead levels in Pasadena and Los Alamos(F) would not be effected by an "adjustment" due to the average hematocrit levels of these two populations.

It is also worth mentioning that although both men and women of the studied Los Alamos couples consumed diets presumably similar in composition, the men consumed a generally greater quantity of food. It is therefore likely that the alimentary exposure of men to lead may be greater than that of women.

Fecal Lead Levels

The analysis of fecal lead levels, (Table 17) conducted to appraise one of these variables, viz., alimentary lead intake, did not demonstrate high or low levels compensating for respiratory exposures so as to obscure effects of the latter. That is, the failure of the Pasadena group to show a "high" blood lead level was not due to a low alimentary lead intake. Conversely the failure to observe "low" blood lead levels in Okeana or Los Alamos was not due to a compensatory high food lead level. It is of interest that the Houston fecal level of lead was relatively high while the blood lead level was relatively low. This observation was not further investigated in this study.

In each area the alimentary level of lead appeared to be much lower than the 300 µg/day commonly quoted as the mean lead intake. This higher number is based upon studies of men, who very probably ingested larger amounts of food than did the women in this study. Nevertheless, the somewhat lower food intakes by women cannot account for the discrepancy. It is possible that current improved food manufacturing practices are associated with reduced lead levels in foods.

Text continued on page 64

Table 16

Frequency Tables Showing Distribution of Hematocrit Values

% Relative Frequency

Hematocrit Interval	Pasadena (F)	Los Alamos (F)	Los Alamos (M)
< 34	0	1.0	0
34-35	4.9	1.0	0
36-37	4.4	4.5	0
38-39	21.2	11.9	2.0
40-41	29.1	17.8	1.0
42-43	18.7	38.1	17.3
44-45	15.8	16.3	34.7
46-47	2.5	6.4	24.5
48-49	3.0	2.0	15.3
> 50	0.5	1.0	5.1

Hematocrit Mean Values and Their 95% Conference Limits

Location	N	Arithmetic Mean	95% Confidence Limits
Pasadena (F)	203	40.97	(40.54, 41.40)
Los Alamos (F)	202	41.97	(41.55, 42.39)
Los Alamos (M)	98	45.55	(45.03, 46.07)

Analysis of Variance Testing Differences in Hematocrit Levels

Source	df	SS	MS	F
Groups	2	1418.62	709.31	80.26**
Error	500	4418.94	8.84	

Further Comparison Between Hematocrit Levels

Comparison	F	Direction
Pasadena (F) vs Los Alamos (F)	11.54**	Los Alamos > Pasadena

** Significant at the 1% level

Table 17

Analyses of Functional Relationship Between Blood Lead and Hematocrit for Non-Smokers

Pasadena (F) N = 131 R = 0.26	Due to regression	3	0.1393	0.0464	3.05*
	Cubic	1	0.0008	0.0008	0.05
	Quadratic	1	0.1381	0.1381	9.08**
	Linear	1	0.0004	0.0004	0.02
	About regression	127	1.9346	0.0152	
Los Alamos (F) N = 104 R = 0.18	Due to regression	3	0.0435	0.0145	1.11 (NS)
	About regression	100	1.3027	0.0130	
Los Alamos (M) N = 32 R = 0.44	Due to regression	3	0.0933	0.0311	2.25 (NS)
	About regression	28	0.3858	0.0138	

*Significant at 5% level.
**Significant at 1% level.

Table 18

Geometric Averages of Fecal Lead Ten Day Totals

Area	N	Fecal Lead (mg/10d.)
Okeana*	20	0.852
Ardmore	20	1.139
Los Angeles	20	1.147
Los Alamos (F)	20	0.973
Washington, D.C.	20	1.168
Port Washington	20	0.967
Lombard	20	0.880
Houston	20	1.505

*Total for donor #0112 adjusted to account for two unusually high values.

Analysis of Variation of Fecal Lead (Ten Day Total) Due to Location

Source	df	SS	MS	F
Location	7	0.9133	0.1304	2.00 (P = 0.08)
Error	152	9.9089	0.0651	

Results of Analysis of Pennypack Data

In April 1961 and April 1971 blood samples from 23 persons in Pennypack were obtained. (Each person was sampled twice: once in 1961 and once in 1971). The geometric mean of 1961 blood lead values is 0.0124 mg/100g; the geometric mean of 1971 values is 0.0138. The ratio of 1971 to 1961 mean values is 0.0138/0.0124 = 111%. The result of a paired T-test performed to test the significance of the difference between mean blood lead values in 1961 and 1971 yielded T = 1.764, df = 22. This value would occur by chance with probability P = 0.09 if in fact the mean lead values in 1961 and 1971 were equal. It was therefore concluded that there may be a real difference between them; more evidence is needed to make definite conclusions. Interpretations must take into account the fact that the sampled participants were ten years older in the latter study than they were in the former.

Results of Analysis of Alpine County Data

In 1960 and 1971 blood samples from two independent samples of males and females from Alpine County, California were measured and recorded.[2,6] The geometric means of each group are as follows:

	Males	Females	Sex Unknown	Total
1960	0.012 (16)	0.009 (11)	0.013 (10)	0.011 (37)
1971	0.0201 (18)	0.0159 (21)	-	0.0177 (39)

The standard errors of the 1971 mean values are 0.0205 for males, and 0.0223 for females. No data on the variation of 1960 values are available.

To determine if there is a difference in the 1971 blood lead values of males and females in Alpine County an unpaired T-test was performed. The resultant T-value was T = 3.393, df = 37. This value would occur by chance with probability P = 0.002 if in fact the mean lead values of males and females were equal. It was therefore concluded that the difference between them is highly significant, that of males being higher. The ratio of 1971 male to female mean values is 0.0201/0.0159 = 126.42%.

Note: The F-statistic testing the equality of variances yielded F = 1.397 (df = 20, 17), P = 0.245.

To determine if there is a statistically significant difference between the average 1960 and 1971 blood lead values, 95% confidence intervals about the 1971 mean values were found. These are, for males and females, respectively, (0.0182, 0.0222) and (0.0143, 0.0176). Since the 1960 mean values, 0.012 and 0.009 respectively, do not lie within these intervals, we conclude that the 1960 and 1971 mean blood lead values are significantly different at the 5% level; for both males and females, the 1971 mean values are higher than those in 1960.

Continuous air sampling over a 6-month period at a representative site in Alpine County permitted the mean atmospheric lead level to be determined: 0.03 $\mu g/m^3$. There is no reason to believe that a higher or lower level prevailed in 1960.

In each of these 2 situations the higher 1971 blood lead determinations may reflect an actual increase or an apparent increase due to differences in methodology used in the two study periods. Standards are not available which would permit a longitudinal comparison of methods. For the Alpine group, the difference is very likely a reflection of method, for there has been no apparent change in the region which would account for the observation. Accordingly the 1960 levels were too low, or the 1971 levels were too high. Insofar as we can determine, from interlaboratory comparisons and from an inspection of data generated in association with the original Alpine County survey[6] and in this study, the 1971 values are of relatively greater validity. There is no evidence that the regional sources of food have changed during the interval between the studies. The possibility that cultural and dietary habits of the 2 sampled populations are dissimilar cannot be excluded from consideration.

Results of Analysis of Policemen Data

In March 1962 and March 1971 blood samples from 45 policemen in Cincinnati were obtained. (Each policeman was sampled twice: once in 1962 and once in 1971.) Blood lead values were measured and recorded. The geometric mean of 1962 blood lead values is 0.0235 mg/100g; the geometric mean of 1971 values is 0.0179 mg/100g. The ratio of 1971 to 1962 mean values is 0.0179/0.0235 = 76%. In order to determine whether the average blood lead value in 1971 is significantly different from that in 1962, a paired T-test was performed. The resultant T-value was T = 8.579, df = 44. This value would occur by chance with probability P = 0.00 (to two decimal places) if in fact the mean lead values in 1962 and 1971 were equal. It was therefore concluded that the difference between them is highly significant. Here again an interpretation requires consideration of the fact that the policemen were older in 1971 than in 1962. The job assignments of a number of policemen had changed over the years; some men had changed from traffic duty to assignments in police cars.

The significance of data derived from the studies of Cincinnati police, Pennypack residents and Alpine County residents is unclear. There are no direct standards which would permit comparison of 1961-62 and the later blood lead assays. Any interpretation of the observed differentials must take into consideration the fact that the determination of lead concentrations in biological materials is a difficult analysis and that experienced laboratories report variable results when presumably identical samples are assayed at different times or under different circumstances. Accordingly, longitudinal comparisons of blood lead levels may contain random and systematic errors which complicate interpretations. While it would seem desirable to run daily standards, it is an unfortunate fact that blood "standards" are often of dubious uniformity and that standards which are introduced into only the final step of the determination fail to reflect the ashing or sample preparation steps.

Experience suggests that day-to-day systematic variability may reduce the validity of comparison studies when samples from different groups are assayed at different times. Consequently it would seem appropriate to intermix samples

from groups to be compared so that samples from all groups are assayed under the same conditions. Such a procedure would dictate that all samples be collected prior to their intermixing and assay. The impracticality of this approach was apparent in this study. Insofar as possible, however, urban and suburban samples from the same metropolitan area were intermixed and assayed simultaneously.

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APPENDIX 1

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APPENDIX 2

Statistical Notes

1) Blood lead concentrations (mg/100 g) were measured to three decimal places. Tables in this study show blood lead measurements to four decimal places. This has been done to prevent rounding to the third decimal place and hence losing accuracy in comparing results.

2) In the analyses of this report, the data are assumed to be normally distributed. Confidence limits and F-tests obtained from analysis of variance techniques depend to varying degrees on the validity of this assumption. It was suggested by previous studies that using the log transformation on blood lead values successfully normalizes the data. To test this assumption the Kolmogorov-Smirnov statistic was calculated for each location separately. (Actually a Z-transformation of this statistic valid for large samples was used.) This statistic was used to test the normality of the logarithm of the blood lead values in each area. The mean values and standard deviations of the normal curves against which the observed data were tested were obtained from the observed data in the usual manner; that is:

$$\bar{X} = \frac{\Sigma X_i}{N}$$

$$S = \left[\frac{\Sigma (X_i - \bar{X})^2}{N-1}\right]^{\frac{1}{2}}$$

where X_i = logarithm of blood lead.

The overall α level in these tests has been set at 0.20; each individual α level, therefore, is equal to 0.01. The table below shows resultant Z-values and their probabilities P(Z).

Table of Z-Values Obtained From Kolmogorov-Smirnov Tests of Normality of Log_{10} Lead Concentrations

Area	Z	P(Z)†
Okeana	1.055	0.22
Ardmore	1.142	0.15
Rittenhouse	0.695	0.72
Pasadena	0.948	0.33
Los Alamos (F)	1.613	0.01*
Washington, D.C.	1.384	0.04
Port Washington	1.180	0.12
Greenwich Village	1.244	0.09
Lombard	1.425	0.03
Bridgeport	1.290	0.07
Houston	1.282	0.07
Los Alamos (M)	0.696	0.72

The conclusion from these tests of normality is that there is one location where the distribution of the logarithm of blood leads differs significantly from normal; however, since this test is conservative, one must question normality in those locations where the Z values have probabilities close to 0.01, namely, Lombard and Washington, D.C. In spite of this, there is enough justification in the table above to assume log normality of the blood lead data, and for this reason all tables of mean values present the geometric mean rather than the arithmetic mean, the geometric mean being the antilog of the arithmetic mean of the logs. In addition, all the analyses of variance are done using log values.

*Significant at 1% level.

†Since two parameters are estimated from the data, it is suggested by Siegel, Non-Parametric Statistics, McGraw Hill, 1956, P.60, that this test is a conservative one.

APPENDIX 3

Geometric Means and Confidence Intervals of Blood Lead (mg/100g) Levels Based on a Single Determination from Each Subject (Based on Total Sample Before Exclusions)

(Rank)	Area	N	Geometric Mean	95% Confidence Limits
5	Okeana	166	0.0158	(0.0150, 0.0166)
9	Ardmore	156	0.0180	(0.0171, 0.0190)
11	Rittenhouse	137	0.0206	(0.0194, 0.0218)
7	Pasadena	209	0.0176	(0.0168, 0.0184)
3	Los Alamos (F)	204	0.0149	(0.0144, 0.0154)
10	Washington, D.C.	224	0.0192	(0.0186, 0.0198)
4	Port Washington	203	0.0154	(0.0149, 0.0159)
6	Greenwich Village	140*	0.0166	(0.0159, 0.0173)
2	Lombard	208*	0.0139	(0.0135, 0.0144)
8	Bridgeport	148	0.0176	(0.0169, 0.0183)
1	Houston	204	0.0124	(0.0120, 0.0129)
	All Females	1999	0.0162	(0.0160, 0.0164)
	Los Alamos (M)	101	0.0172	(0.0164, 0.0180)

*No change in N.

Age Distribution of Females in Okeana, Philadelphia, Pasadena, and Los Alamos

% Relative Frequency

Age Interval (yrs.)	Okeana	Ardmore	Rittenhouse	Pasadena	Los Alamos
20-29	14	2	3	3	0
30-39	22	11	6	23	32
40-49	31	23	12	25	54
50-59	23	30	32	10	11
60-69	6	26	31	15	3
70-79	4	7	16	24	0
Total N	162	150	136	192	191

Age Distribution of Females in Washington, D.C., New York, Chicago, and Houston

% Relative Frequency

Age Interval (yrs.)	Washington, D.C.	Port Washington	Greenwich Village	Lombard	Bridgeport	Houston
20-29	1	3	6	3	14	8
30-39	7	21	29	24	20	27
40-49	21	27	28	37	34	42
50-59	24	32	15	25	20	19
60-69	25	12	14	10	10	3
70-79	21	5	8	1	2	1
Total N	219	198	140	208	147	191